NICOLAS TERRY
PRESENTS

Folding Fantasy
Volume 2

PBS Origami

PETER BUCHAN-SYMONS

Folding Fantasy

Volume 2

Peter Buchan-Symons

For Esther Wang, who has infectious enthusiasm and perseverance.

With special thanks to some key people. Firstly, to Florian Videau for a huge amount of time testing all of the models in this book. Your feedback has made the sequences far clearer and more enjoyable! Secondly, to Michael Nguyễn for a phenomenal interpretation of my Dwarf Brawler. Also to Robert Lang and Mu-Tsun Tsai for reviewing some of the mathematical content and providing encouragement of the highest kind.

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A double thanks to Peter Whitehouse (again!), Edward Shaw, Natasha Symons, and my mum, Cynthia, for editing the text throughout this book. You've given perhaps the most important help of all to make the text clearer and more accurate. Thank you for all the time you've put in to find my mistakes!

Contents

1 Introduction

Wonky gravestone 2

Two-headed goose 4

Winged doe 8

Difficulty

- Simple
- Low Intermediate
- High Intermediate
- Complex
- Supercomplex

There are no simple models in this book. This difficulty level is here for consistency with other, easier books.

Gnome 14
Nettle 22
Behind the design 30

Cutethulhu 36
Behind the design 43

Psyche 48
60 Behind the design
Minotaur 72
Behind the design 88

Hydra 92

Scorpion 109

117 Behind the design

Aqrabuamelu 123

137 Behind the design

Spider 143

Dwarf brawler 152

Behind the design 174

182 Contributors

184 Other books by the author

186 Legal information

Introduction

This book is not just another catalogue of complex models that you can tick off your origami checklist. Instead of supplying you with an ever-increasing level of challenge, I want to give you a taste of what being an origami designer is like.

This sentiment should come across most strongly in the 'Behind the Design' chapters. Compared to Volume 1, I've tried to show a broader array of topics. These range from technical design methods, including the development of new folding theory, to sections that discuss the highs and lows of designing the model in question (and therefore don't necessarily give any practical design tips). So if there seems to be no through-line between the topics, that's sort of the point: to show the range of experiences I've had as a designer.

I hope that you can feel this variety as you fold the models. Some were planned methodically via the crease pattern and were fully formed before I ever experimented with the paper. For example, the Hydra has a rigid structure and a technical process for finding references in the first few steps.

On the other end of the spectrum, models like the Winged Doe were devised in a much more playful way, guided by an idea of the feel of the subject and the natural limits of the paper. I'd normally be tempted to make this sort of model easier by finding explicit references, but I've decided not to because that would obscure the truth of how the design came to be. I hope that through the repeated moments of not knowing exactly where to fold, you can learn to appreciate this authenticity.

I should mention that although this is Volume 2 in a series, there's no need to have folded the models in *Folding Fantasy: Volume 1*. I've tried my best to make topics in the 'Behind the Design' chapters understandable in their own right too. However, I do mention and build upon previously discussed ideas, so you will get the most out these chapters if you've read the information in Volume 1. Whether you are new to this series or not, I hope you enjoy this second set of models and are able to learn about origami design more deeply; not just by reading and absorbing the information here but by also experimenting for yourself, and discovering your own secrets.

Note

There are deliberately no pages which explain diagramming terminology, symbols, or manoeuvres because this information can be found in *Folding Fantasy: Volume 1*, and it should already be familiar to all folders who have the ability to make the models in this book.

I've made this information freely available at pbsorigami.co.uk, should you want a refresher.

Wonky Gravestone

First time: 15cm/6''

Paper preferences:
- Thick
- Textured

Recommended papers:
- Tant
- Elephant Hide

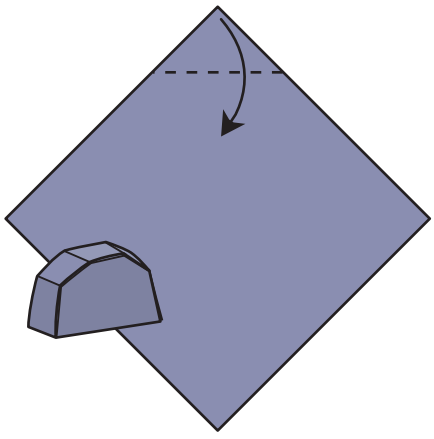
Note

To create a Wonky Gravestone with a smooth, round top, bend the central strip of paper in step 11 (and whenever step 11 is repeated) rather than folding firmly.

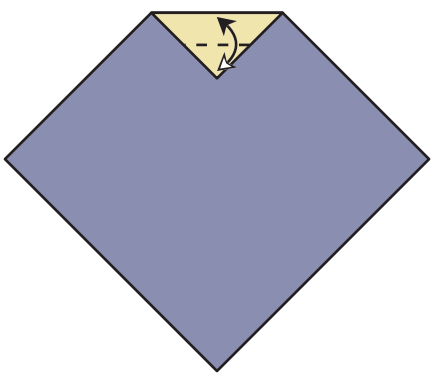
I'm going to ask you to be brave with this model. I've deliberately not included references for steps 1, 11, or 15, or a crease pattern. I've left these open for you to use your judgement!

This is a safe space for you to exercise your creativity, since any folds in the vague areas shown in these diagrams will lead to a suitable final model. Moreover, it's much easier to create a unique, weathered-looking gravestone with this approach than with a rigid (and much longer) folding sequence.

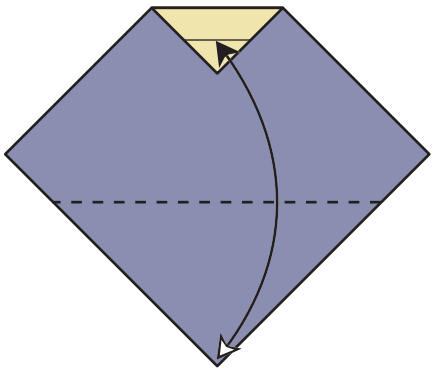
Start stone colour side up.



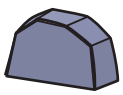
1. Fold the top raw corner down about as far as shown here.

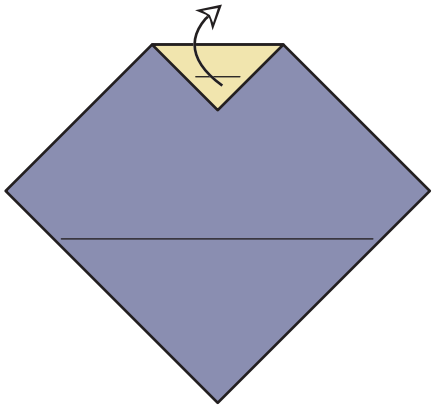


2. Fold the raw corner to the centre of the folded edge, then unfold.

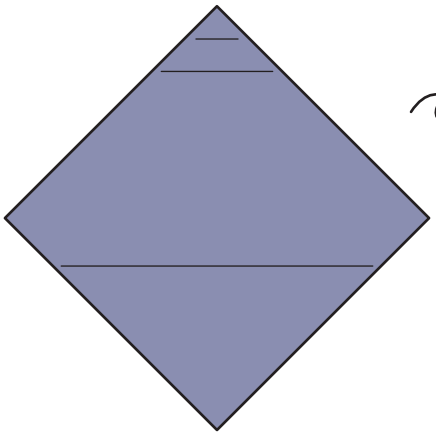


3. Fold the bottom raw corner up to the crease, then unfold.

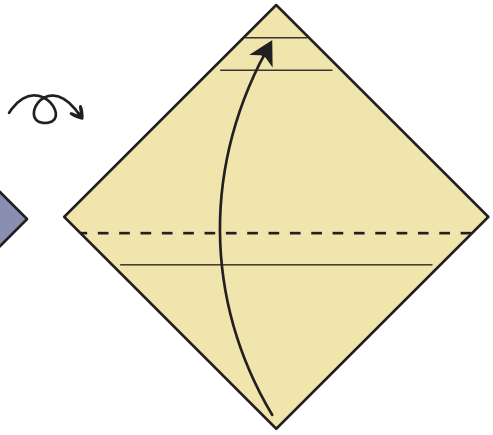




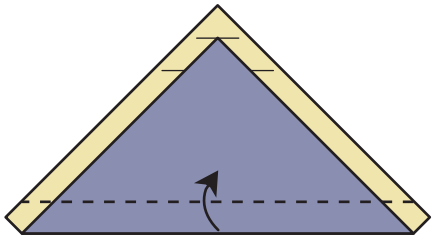
4. Unfold the raw corner.



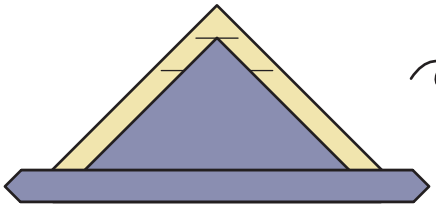
5. Turn the paper over.



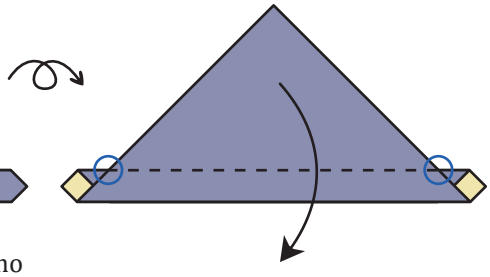
6. Fold the bottom raw corner up to the topmost crease.



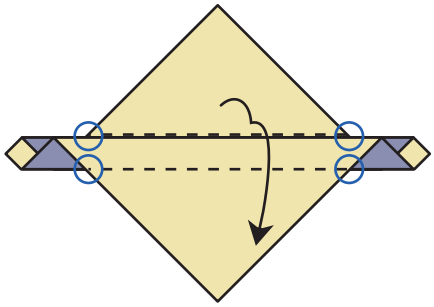
7. Fold the edge upwards using the existing crease in the near layer.



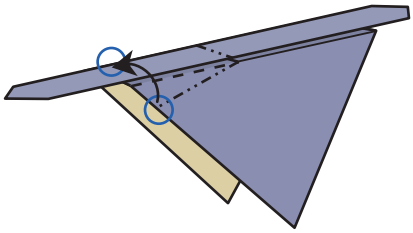
8. Creases from steps 1 and 2 will no longer be shown. Turn the paper over.



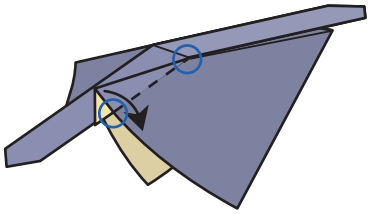
9. Fold the raw corner down using a new valley fold which aligns with the folded edge, as shown.



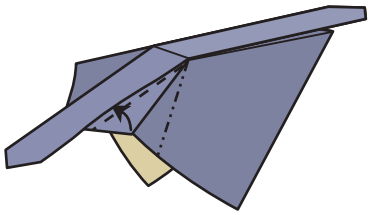
10. Make two new valley folds that align with existing edges. Don't flatten these, but leave the adjacent sections of paper perpendicular to each other.



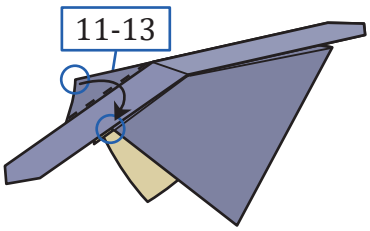
11. Bring the circled point on the nearest raw edge across to meet the far folded edge, as shown. There are deliberately no other references.



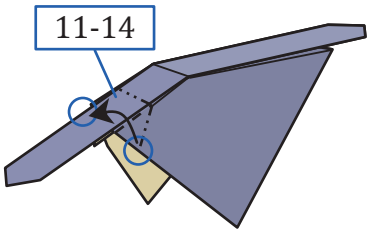
12. Fold the corner down using a fold-line which is directly above the long folded edge.



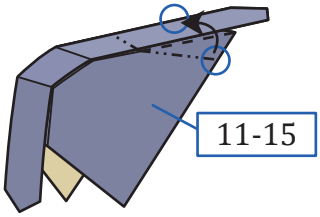
13. Tuck the corner underneath the folded edge so that the nearest face becomes flat and vertical.



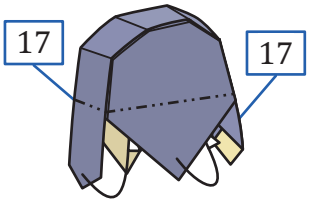
14. Repeat steps 11 to 13 behind.



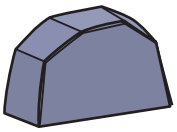
15. Repeat the same sequence as steps 11 to 14.

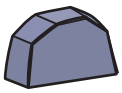


16. Repeat steps 11 to 15 on the right.



17. Mountain-fold the raw corners inside so that the model stands.



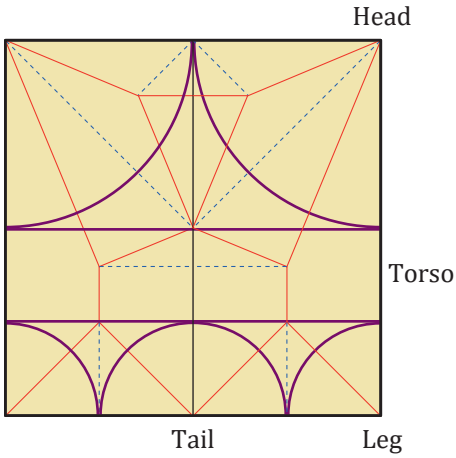


TWO-HEADED GOOSE

First time: 25cm/10''

Paper preferences:
- Duo
- Textured

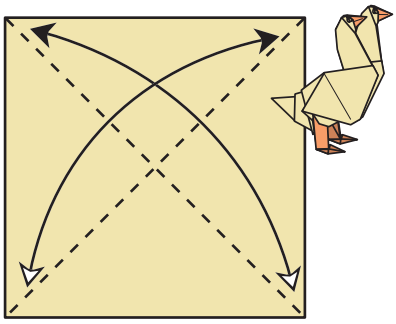
Recommended papers:
- Tissue Foil
- Kami
- Sandwich paper
- Double tissue



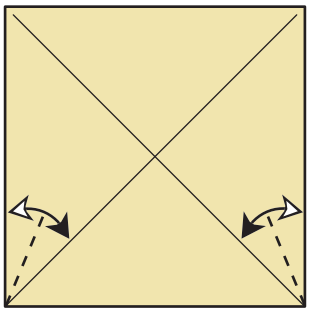
I've deliberately made this model in the same style as my previous (regular, one-headed) Goose design in *Easy Springtime Origami*: even though the underlying structure is completely different, each of the individual flaps are the same shape.

For a simpler model, you can omit the most challenging steps: 26 to 27, 31 to 37, and 39 to 40.

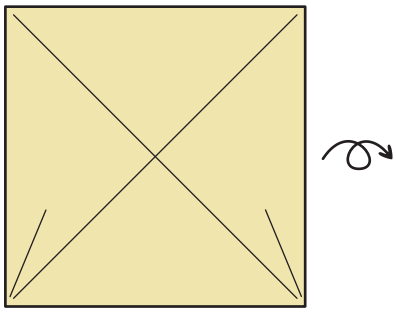
Start feathers colour side up.



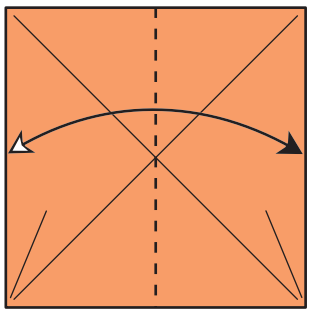
1. Fold and unfold the diagonals.



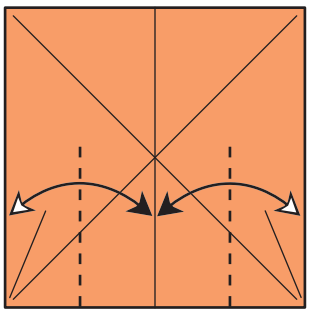
2. Fold two angle bisectors, but only mark the paper firmly near the bottom raw corners.



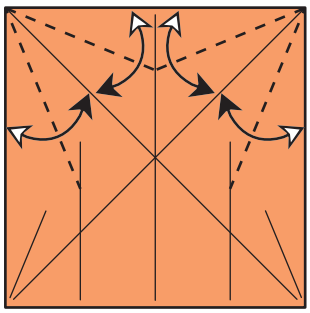
3. Turn the paper over.



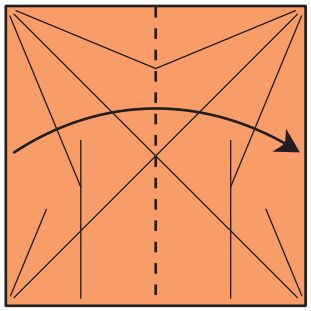
4. Fold the central vertical line and unfold.



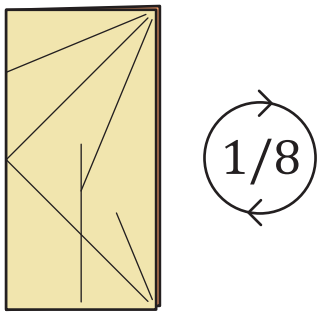
5. Fold the raw edges to the centre and unfold, only marking firmly in the lower half of the paper.



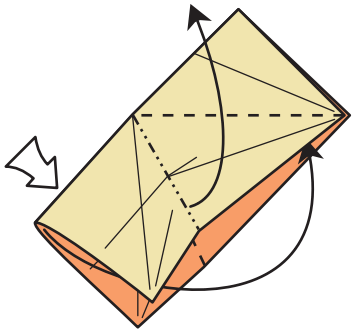
6. Fold and unfold four angle bisectors where shown.



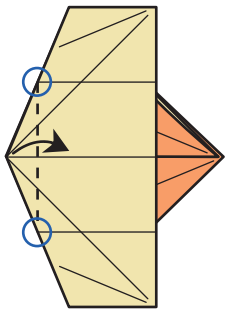
7. Fold the left half onto the right half.



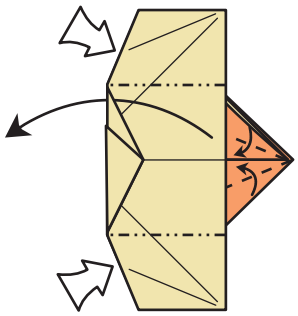
8. Rotate the paper ⅛ of a turn clockwise.



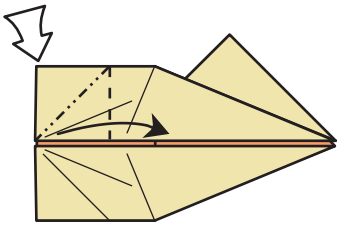
9. Lift the raw edge using the existing horizontal valley fold and squash-fold the paper to the right.



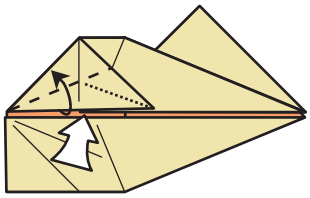
10. Fold the corner to the right using a vertical line through the circled points.



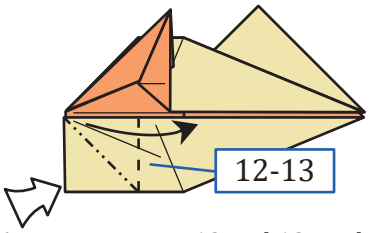
11. Petal-fold the raw edge to the left.



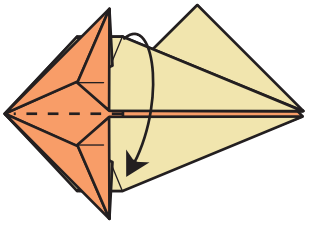
12. Swivel-fold the upper raw corner to the right.



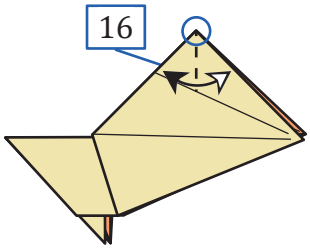
13. Swivel-fold: bring the raw edge up along a new angle bisector, and flatten using an existing crease.



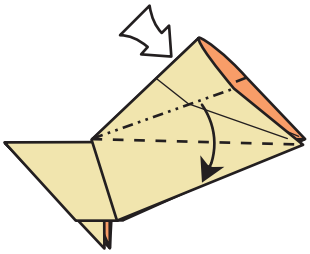
14. Repeat steps 12 and 13 on the lower raw corner.



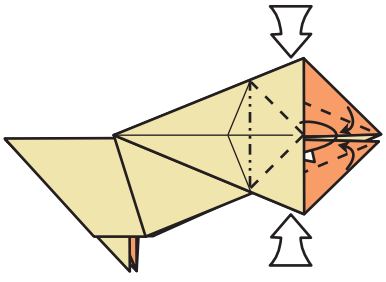
15. Fold the near flap down onto the bottom section.



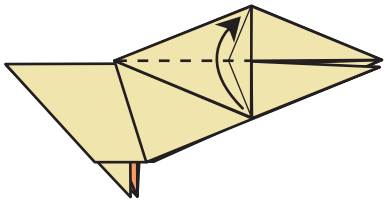
16. Fold and unfold a vertical line where shown. Repeat behind.



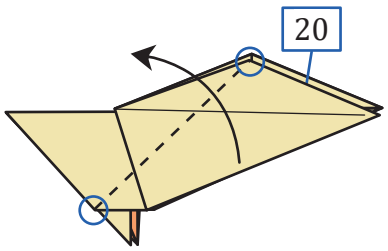
17. Squash-fold the edge.



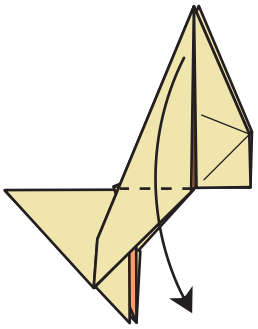
18. Petal-fold the edge underneath to the left. The only new fold-line is the vertical mountain fold.



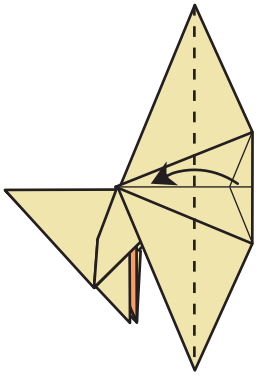
19. Fold one flap up.



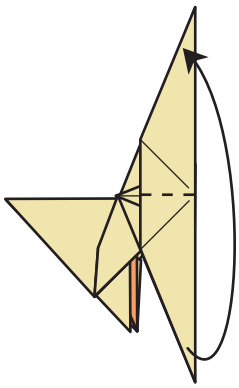
20. Fold the edge up and to the left. Repeat behind.



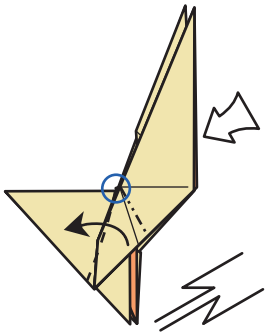
21. Fold the large flap down as far as it will go.



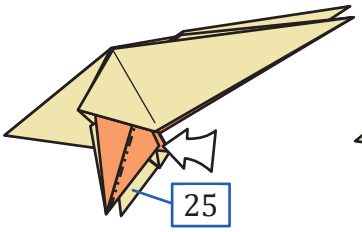
22. Fold one layer to the left.



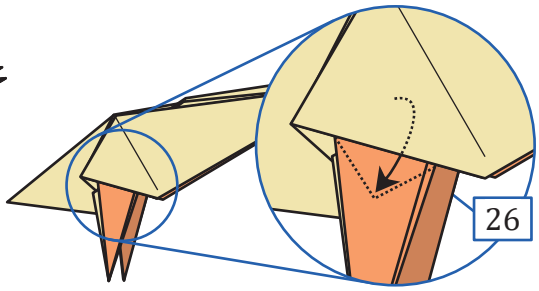
23. Fold the flap back up.



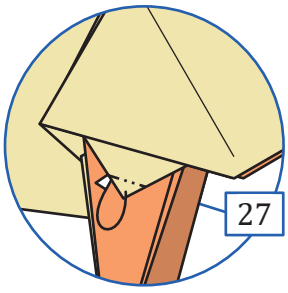
24. Crimp the whole right section around the left section, pivoting about the circled point. Don't worry about the exact angles of the folds – you can adjust these later.



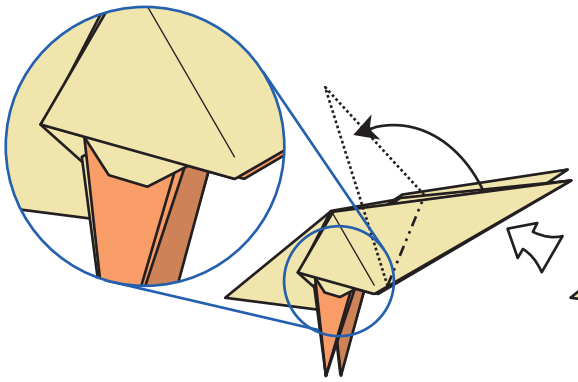
25. Reverse-fold the raw edge of the near flap. Repeat behind.



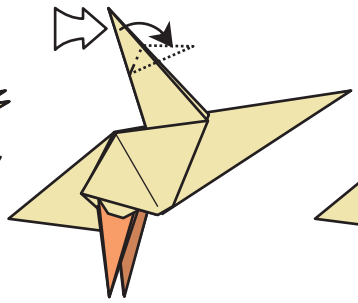
26. There are no references from now on. Pull the hidden corner down a bit, but not fully. Repeat behind.



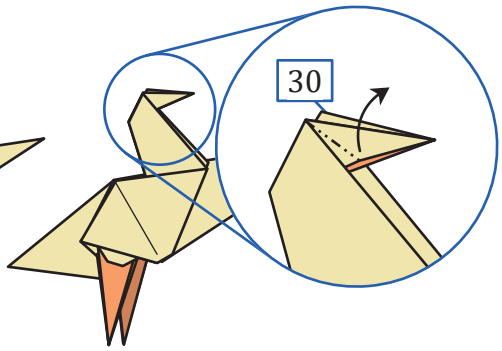
27. Mountain-fold the corner underneath. Repeat behind.



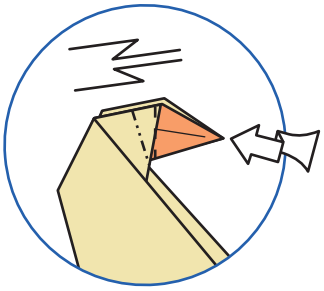
28. Reverse-fold the nearest of the two long flaps.



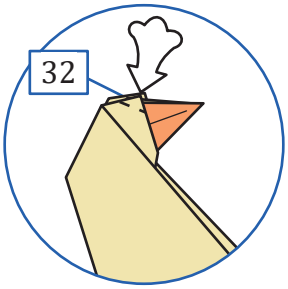
29. Reverse-fold the end of the flap to the right.



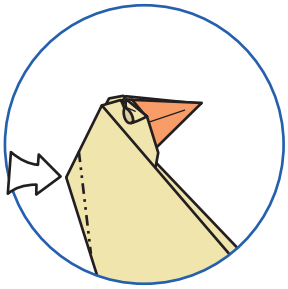
30. Carefully pull the raw edge out to reveal a coloured triangle. Repeat behind.



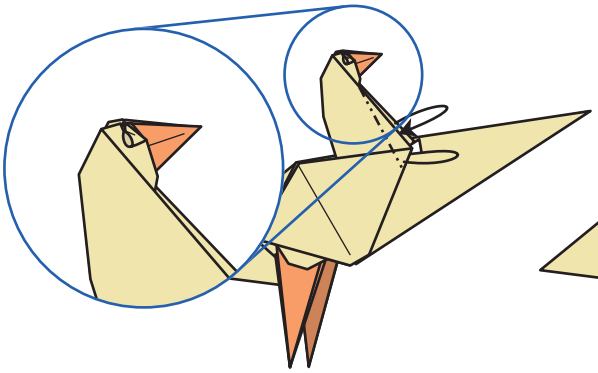
31. Crimp the corner in and out.



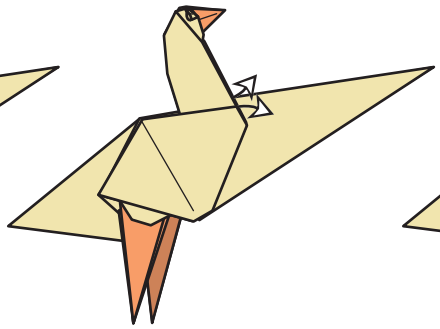
32. Squash and open the corner to form an eye. Repeat behind.



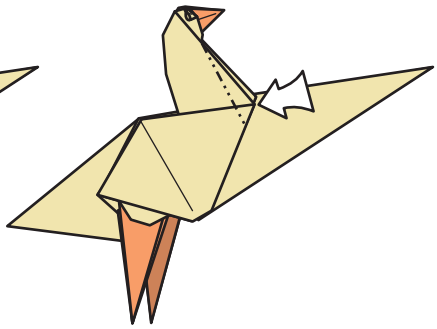
33. Closed-sink the corner at the back of the head.



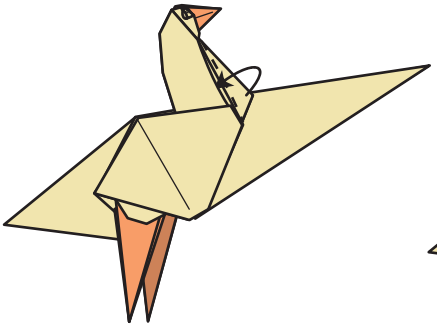
34. Mountain-fold the edges in to make the neck narrower.



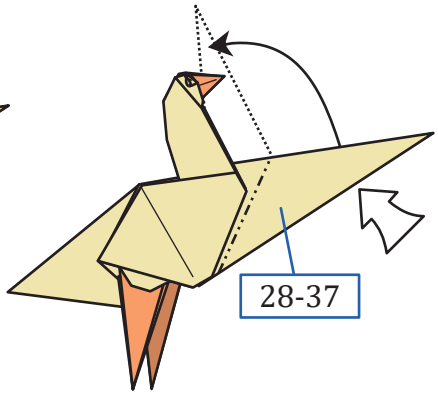
35. Unfold step 34.



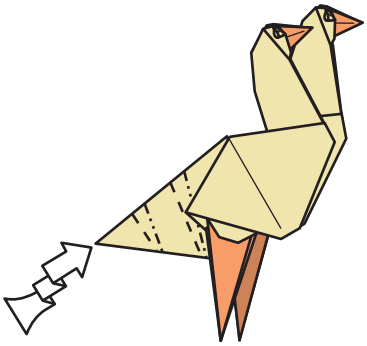
36. Closed-sink the near edge in.



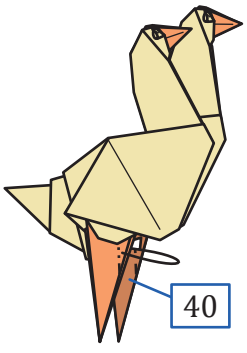
37. Fold the far edge into the pocket.



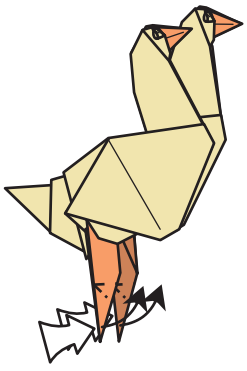
38. Repeat steps 28 to 37 on the far flap. You can use different angles this time to make each head unique.



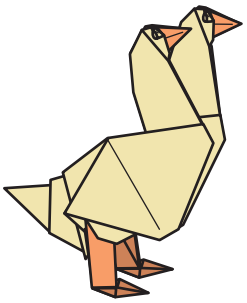
39. Crimp the tail in a couple of places to suggest tail feathers.



40. Mountain-fold the front part of the leg behind to make it narrower. Repeat behind.



41. Squash-fold the two feet so that the model stands.

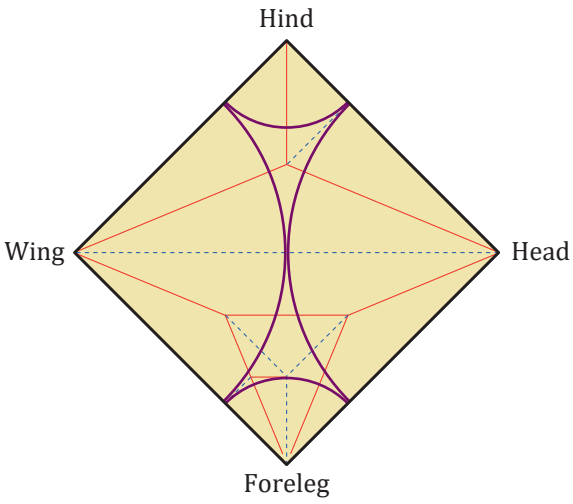


Winged Doe

First time: 20cm/8''

Paper preferences:
- Duo
- Shapeable
- Textured

Recommended papers:
- Kami
- Duo Kraft
- Sandwich paper

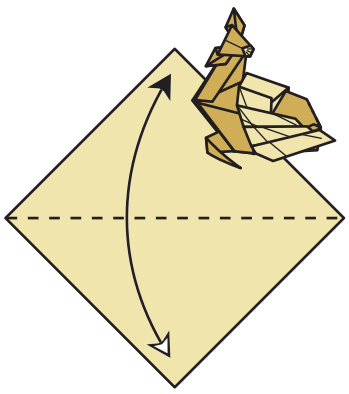


The Winged Doe is an example of a one-sided model. This makes it relatively quick compared to other models with a similar step count because there are (almost) no 'repeat behind' steps.

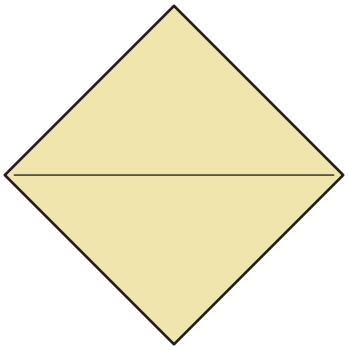
From step 15 onwards, the majority of new creases do not have references. Don't expect your first attempt at this model to end up perfect. Just enjoy the process of folding the Doe multiple times to learn your own preferences for where to fold, and notice yourself improving over time.

You may enjoy adapting this model into other winged creatures, for example to make a resting Pegasus.

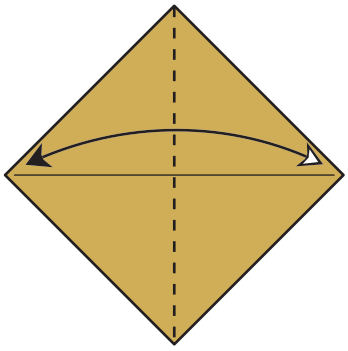
Start wing colour side up.



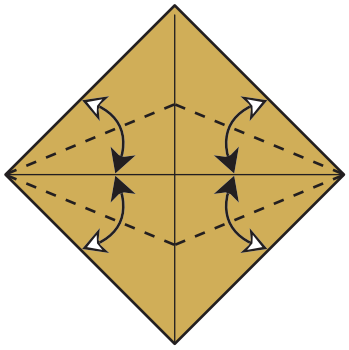
1. Fold the horizontal diagonal and unfold.



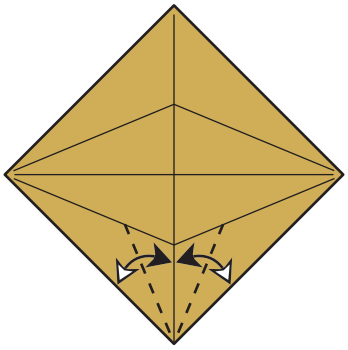
2. Turn the paper over.



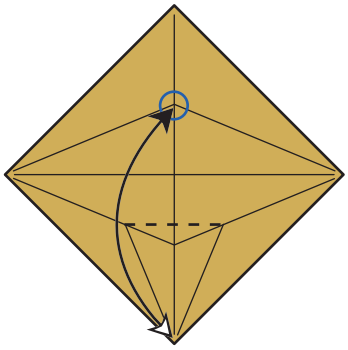
3. Fold the vertical diagonal, then unfold.



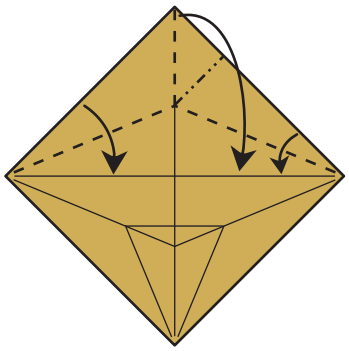
4. Fold and unfold four angle bisectors.



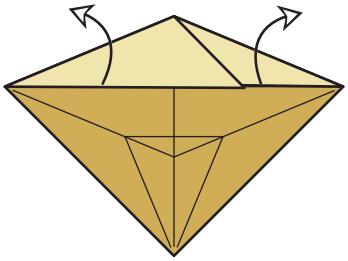
5. Fold and unfold two angle bisectors.



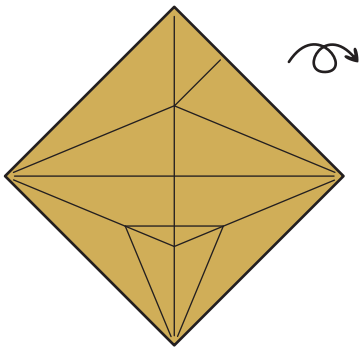
6. Fold the bottom raw corner to the circled point, then unfold.



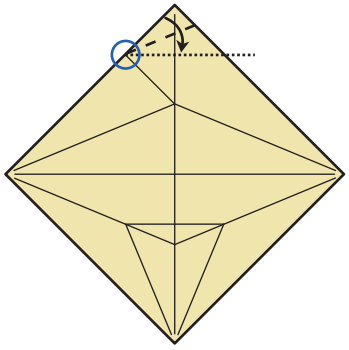
7. Rabbit-ear the top raw corner down and to the right.



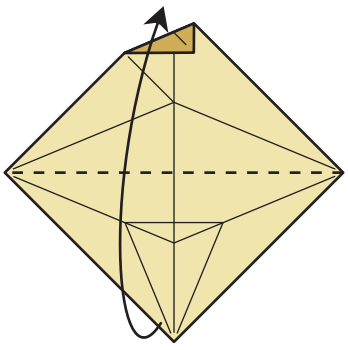
8. Unfold step 7.



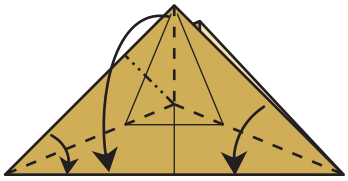
9. Turn the paper over.



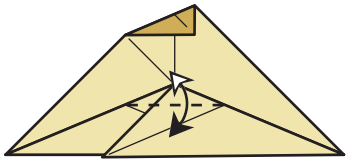
10. Fold the top raw corner down so that the left raw edge lies along the indicated imaginary line.



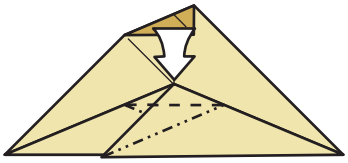
11. Fold the bottom half of the paper onto the top half.



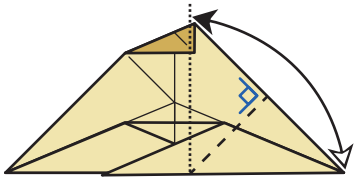
12. Rabbit-ear the raw corner down and to the left.



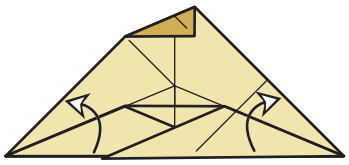
13. Fold the near corner down to transfer an existing crease to the near layers, then unfold.



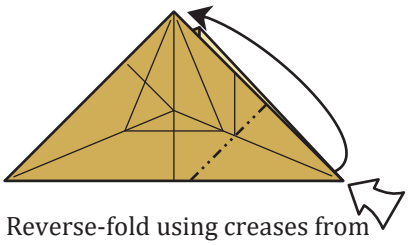
14. Open-sink using existing creases.



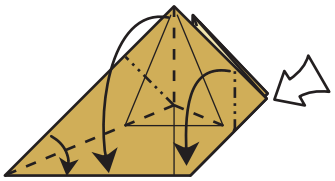
15. Fold the right raw corner to the top – it should go a little beyond the coloured triangle. Then unfold.



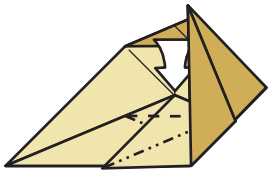
16. Unfold back to step 12.



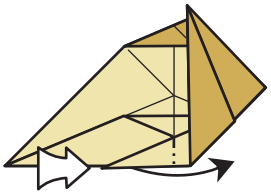
17. Reverse-fold using creases from step 15.



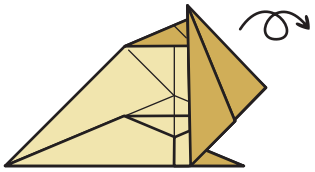
18. Refold the rabbit ear from step 12, but this time you have to swivel-fold the raw edge on the right.



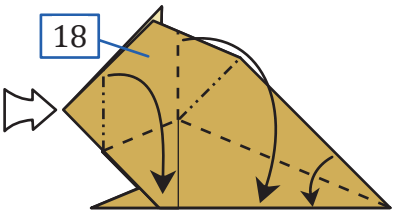
19. Refold the sink from step 14.



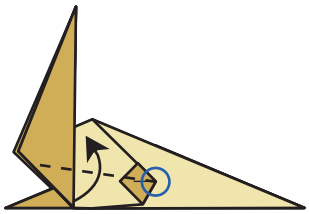
20. Reverse-fold the raw corner to the left.



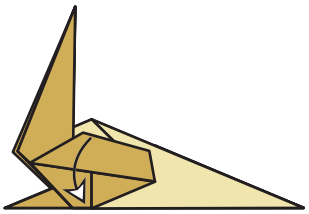
21. Turn the paper over.



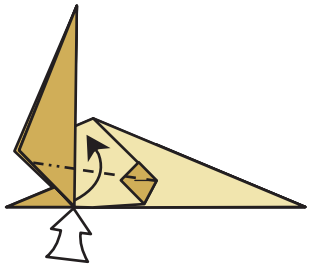
22. Repeat step 18.



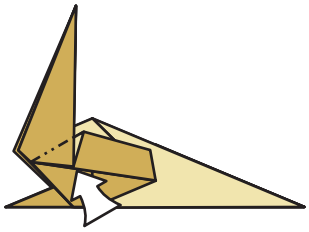
23. Fold the edge up. The fold-line goes through the circled point.



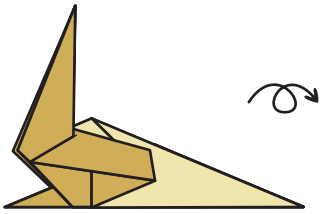
24. Unfold step 23.



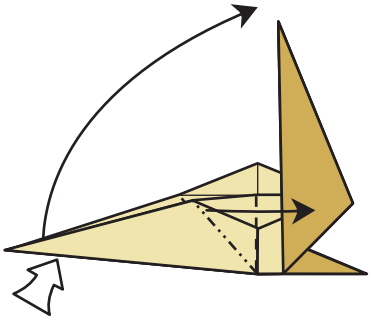
25. Reverse-fold the edge up under the raw edge on the left.



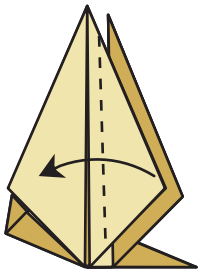
26. Reverse-fold the corner.



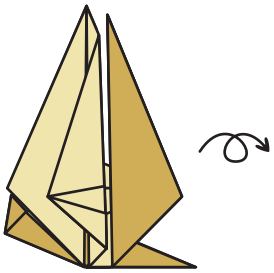
27. Turn the paper over.



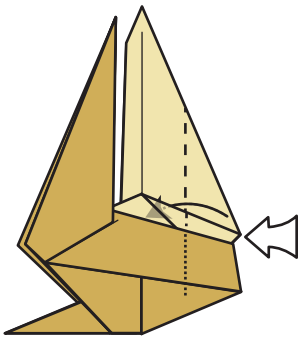
28. Squash-fold the raw corner upwards.



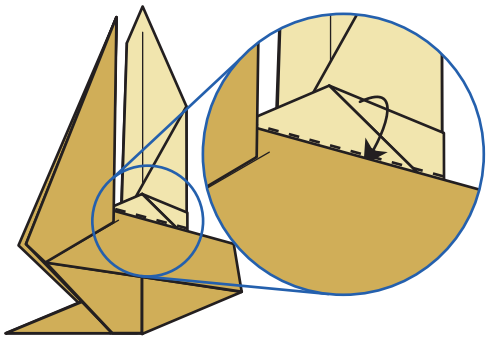
29. Fold the corner to the left so that the white flap no longer overlaps with the coloured triangle behind.



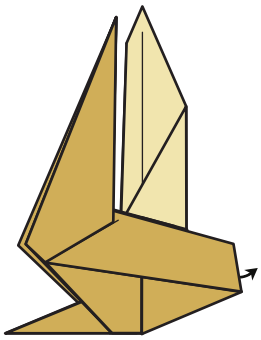
30. Turn the paper over.



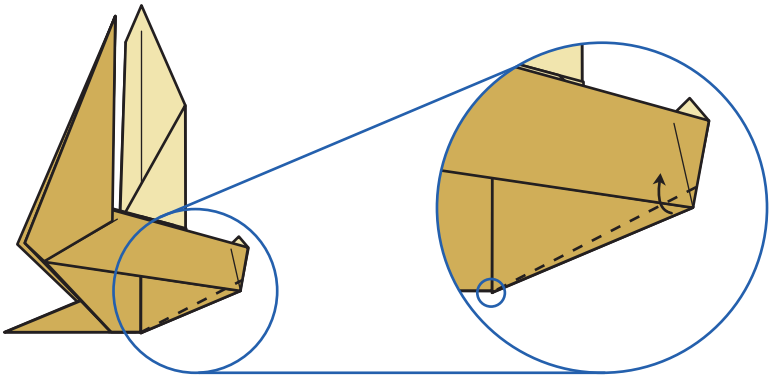
31. Reverse-fold the corner to the left using an (approximately) vertical line.



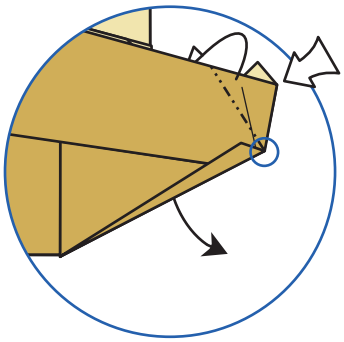
32. Fold the white region down along the line of the raw edge, and tuck it under the raw edge.



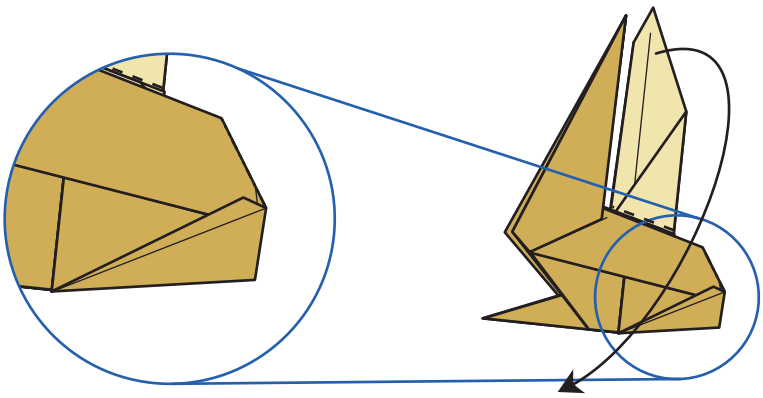
33. Pull the raw corner out.



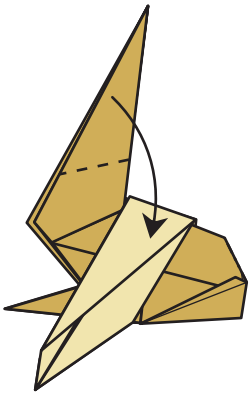
34. Fold a small amount of paper up. Only fold firmly in the near layer.



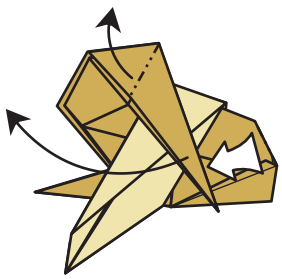
35. Swivel-fold: pull out the raw edge at the bottom and pivot the raw corner underneath anticlockwise.



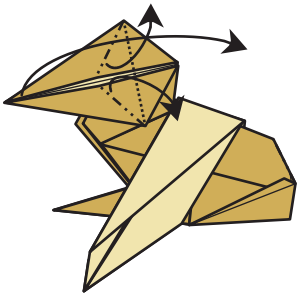
36. Fold the white flap down.



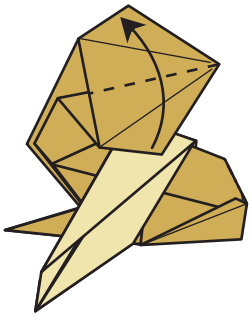
37. Fold the corner down.



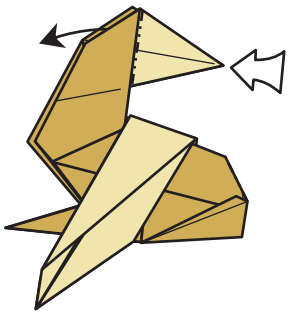
38. Squash-fold the corner to the left.



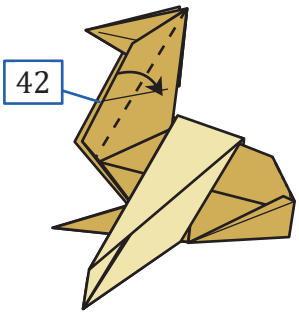
39. Fold the corner to the right, and pull the raw edges out.



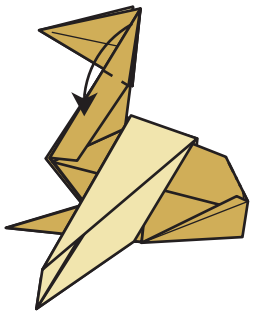
40. Fold the flap up.



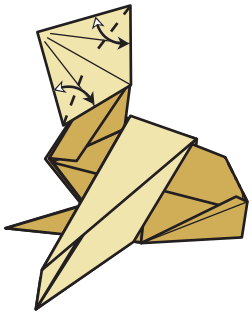
41. Reverse-fold the raw corner along the line of the raw edge.



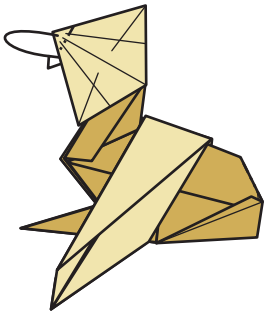
42. Fold the edges to the right. (This is not necessarily an angle bisector.) Repeat behind.



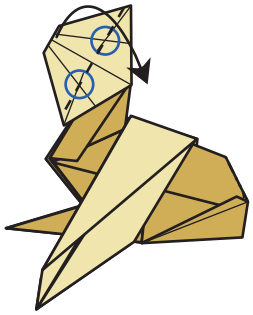
43. Fold the near corner down.



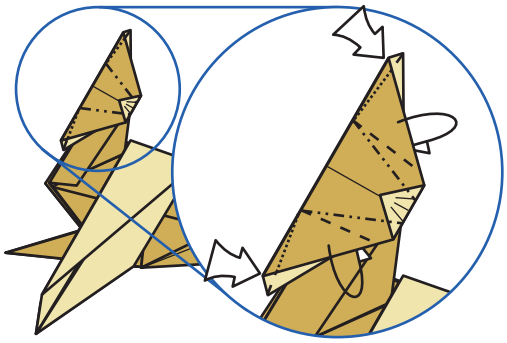
44. Fold and unfold two angle bisectors.



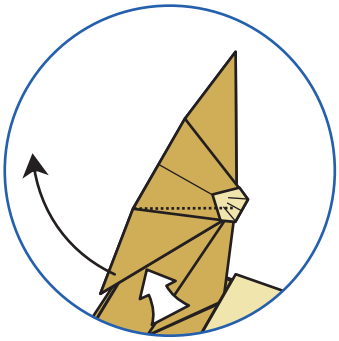
45. Mountain-fold the raw corner behind.



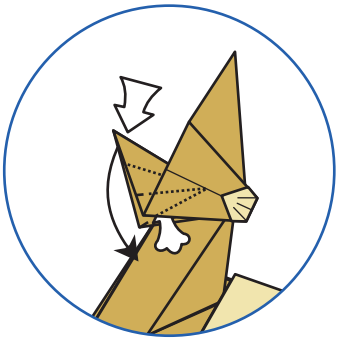
46. Fold the paper to the right using a fold-line which passes through the circled points.



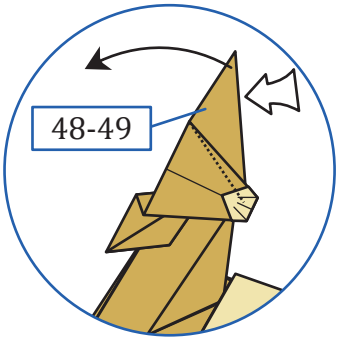
47. Swivel-fold the raw edges underneath using creases from step 44.



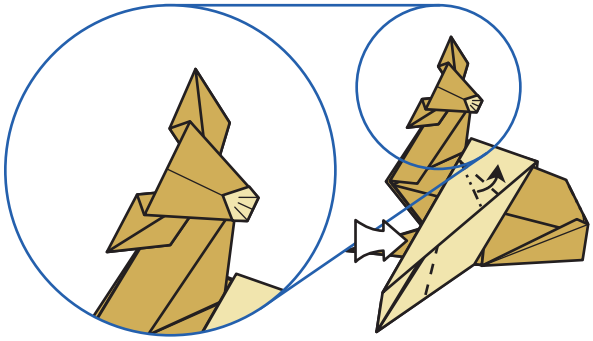
48. Reverse-fold the corner to the left.



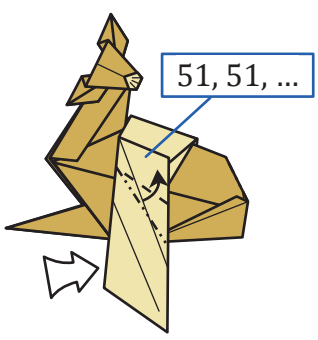
49. Open the corner and twist it downwards to make an ear.



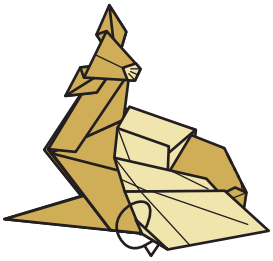
50. Repeat steps 48 and 49 on the upper corner.



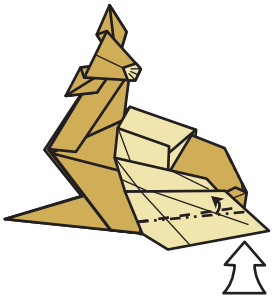
51. Pleat the near layers of the wing, and swivel-fold the wing to the right.



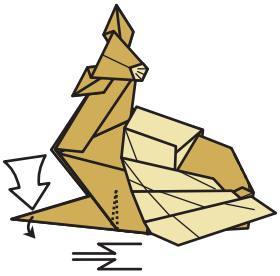
52. Repeat step 51 until a hidden edge appears (see next image). This will probably be two or three times.



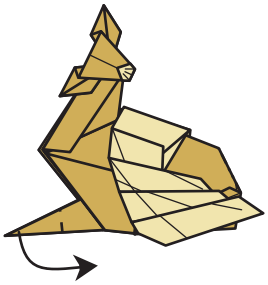
53. Wrap the edge to the back.



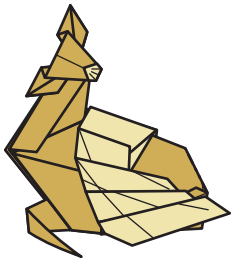
54. Continue to pleat until you reach the edge of the wing. You will have to pleat through the far layers of the wing too, unlike with steps 51 and 52.



55. Crimp the foreleg down slightly.



56. Fold the foreleg at the knee so that the model stands freely.

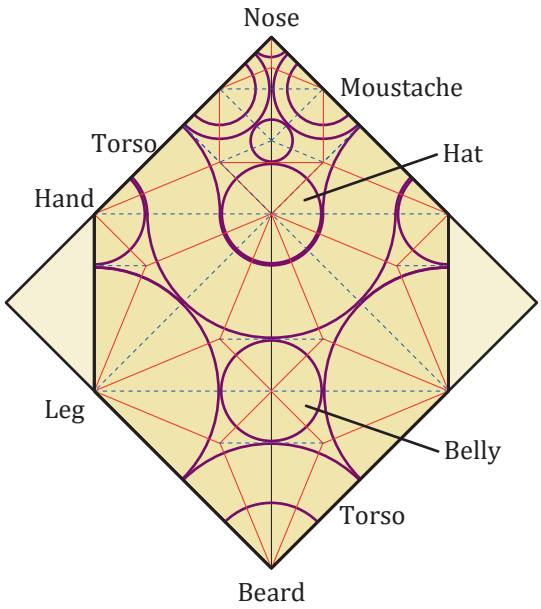


Gnome

First time: 25cm/10''

Paper preferences:
- Duo
- Textured

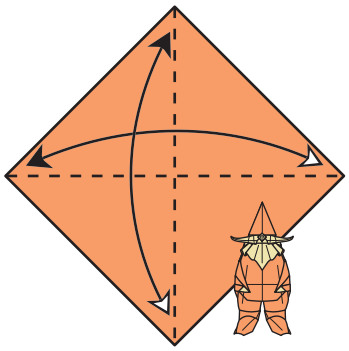
Recommended papers:
- Kami
- Duo Thai
- Duo Kraft
- Sandwich paper



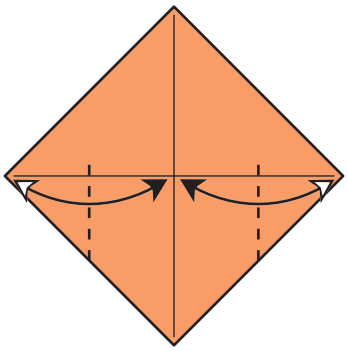
It's relatively tricky to fold a well-proportioned origami face, so here's a tried-and-tested trick (for lazy designers?): don't. The Gnome's hat covers the eyes and ears, and the beard hides the chin, as well as the neck and shoulders.

The base for this Gnome is one of my favourites. It has several appealing properties such as: familiar substructures, a mix of shorter and longer flaps, a river, and plenty of edge flaps and spare paper for colour changes. Have a go at making your own model from it (use only steps 1 to 8, 13 to 21, and 29 to 31 to avoid the Gnome-specific steps).

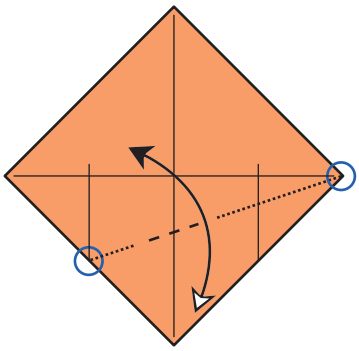
Start clothes colour side up.



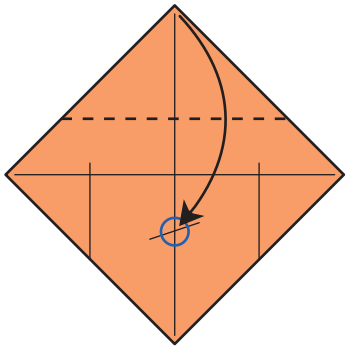
1. Fold and unfold the diagonals.



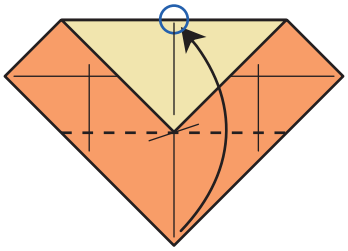
2. Fold the raw corners to the centre, mark the paper firmly where shown, then unfold.



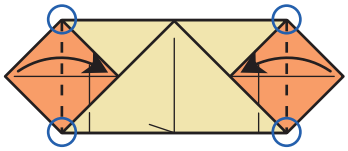
3. Make a fold-line which connects the circled points. Only fold firmly over the vertical crease, then unfold.



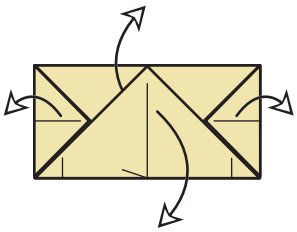
4. Fold the top raw corner to the circled point.



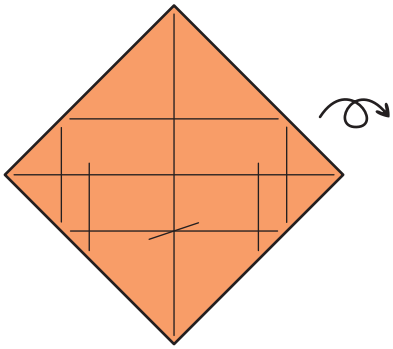
5. Fold the bottom raw corner to the circled point.



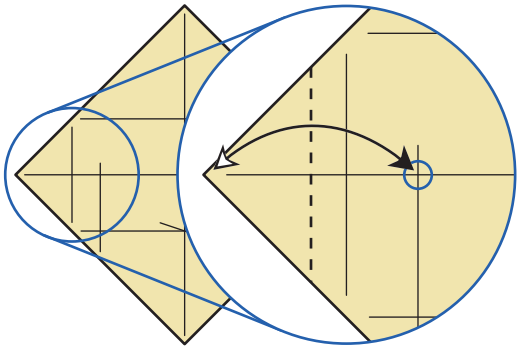
6. Fold the raw corners in.



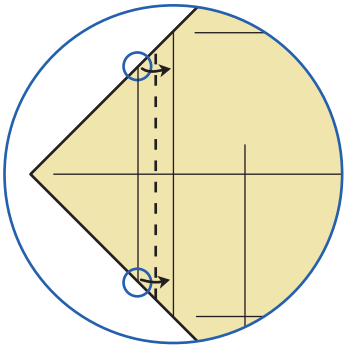
7. Unfold everything.



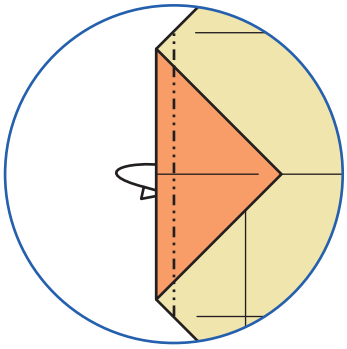
8. Turn the paper over.



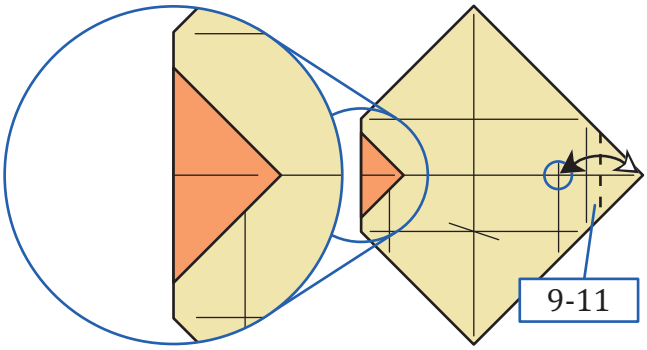
9. Fold the raw corner to the circled point, then unfold.



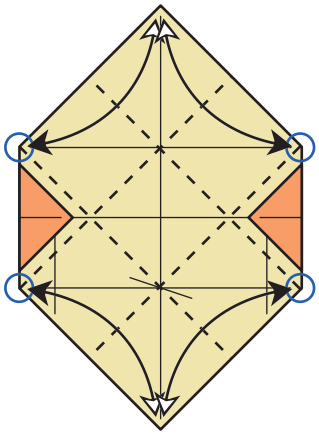
10. Fold so that the crease you just made lies on the next vertical crease.



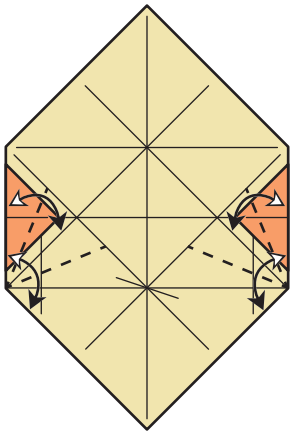
11. Mountain-fold the edge behind using existing creases.



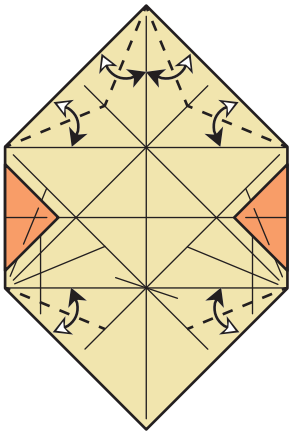
12. Repeat steps 9 to 11 on the right.



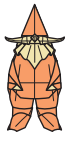
13. Fold and unfold.

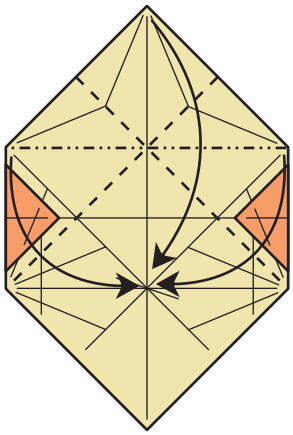


14. Fold and unfold four angle bisectors.

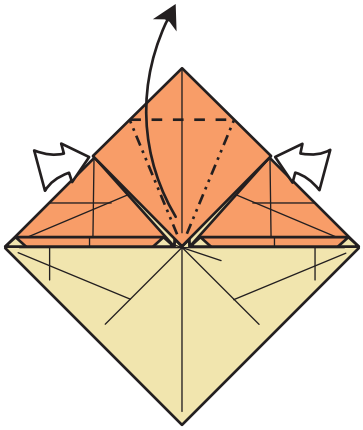


15. Fold and unfold six angle bisectors.

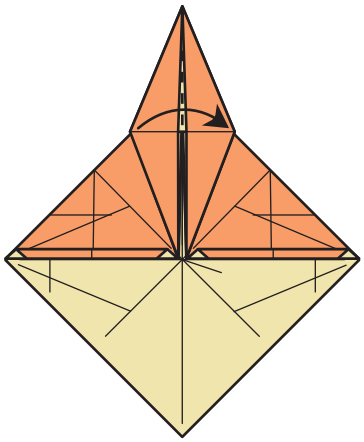




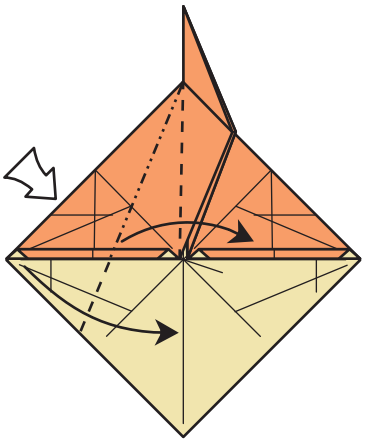
16. Preliminary-fold using existing creases.



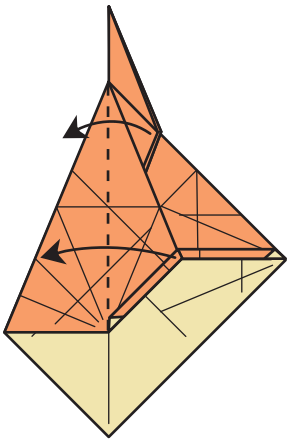
17. Petal-fold the raw corner upwards.



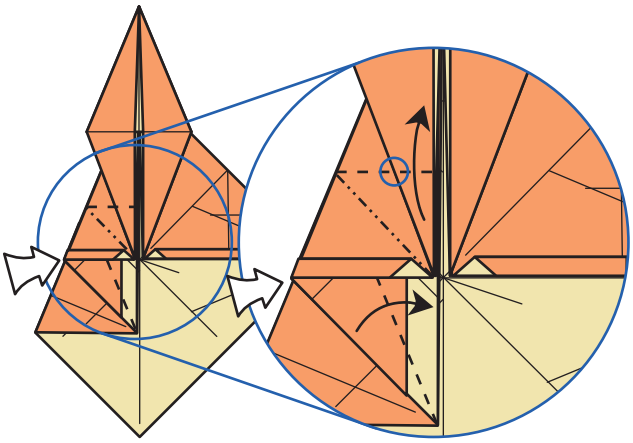
18. Fold one layer to the right.



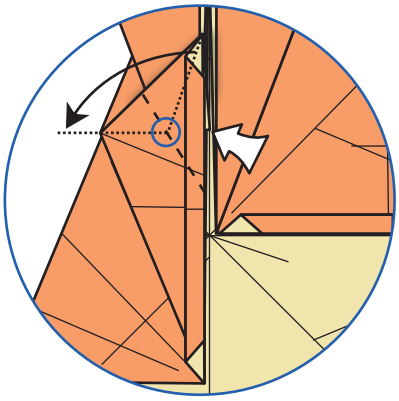
19. Squash-fold the edge.



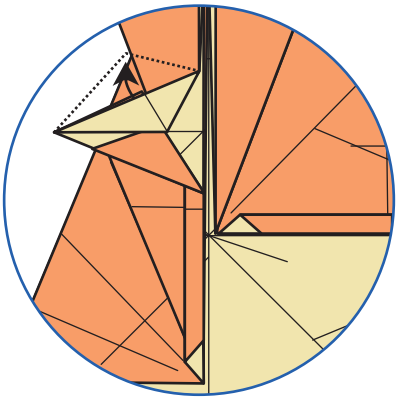
20. Fold two layers to the left.



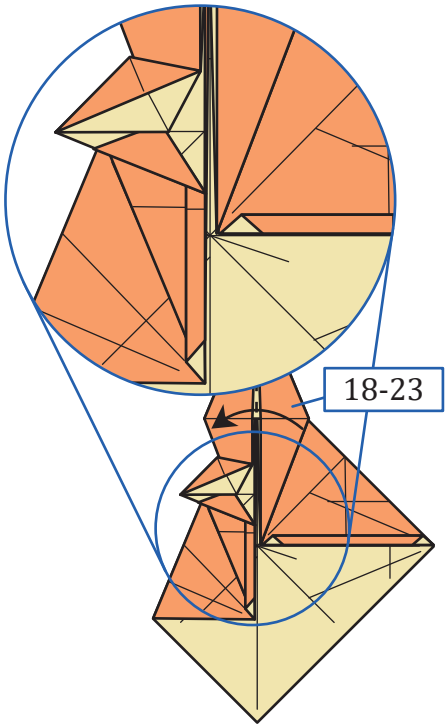
21. Swivel-fold using existing creases. Only fold in the nearest layer at the bottom of the lower valley fold (so the entire hidden white triangle becomes visible). Note the circled point where the valley fold crosses the folded edge – this will be used in step 22.



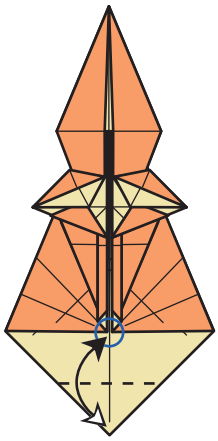
22. Bring the hidden folded edge down to the left so that it becomes horizontal, and squash-fold the white corner upwards using entirely new fold-lines. The circled point is the same as in step 21. This step doesn't have to be exact.



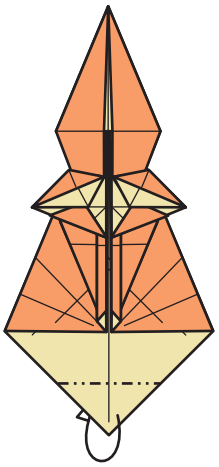
23. Reverse-fold the hidden folded edge upwards, as shown. You may need to unfold the paper slightly.



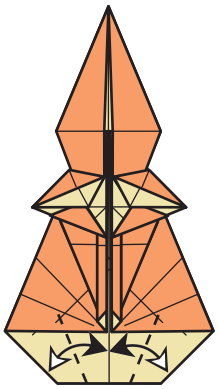
24. Repeat steps 18 to 23 on the right.



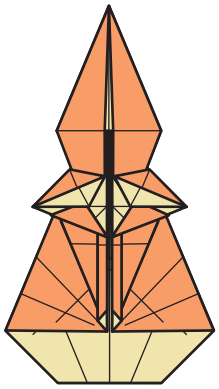
25. Fold the raw corner to the circled point, then unfold.



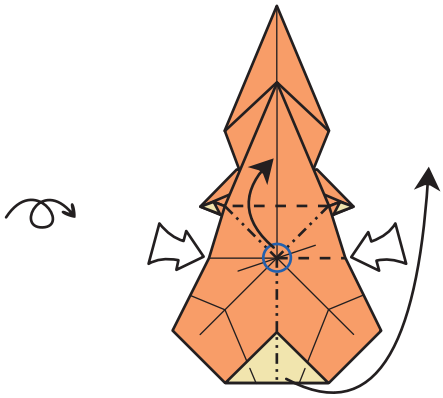
26. Mountain-fold the raw corner behind using the crease you just made.



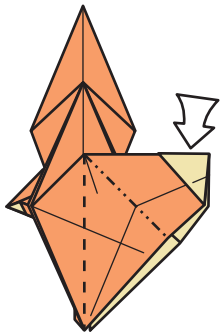
27. Fold the raw edges to the central vertical crease, but only mark firmly where shown.



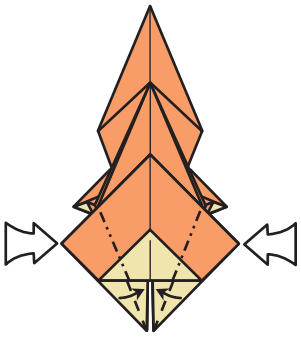
28. Turn the paper over.



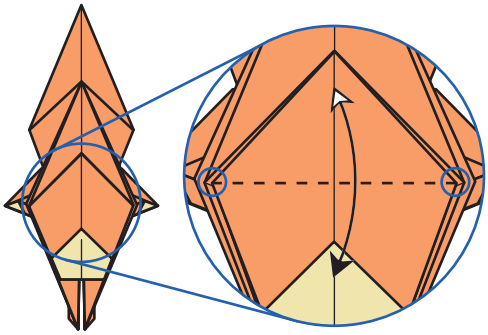
29. Use mostly existing creases to bring the circled point upwards and squeeze the sides in where shown. Then flatten the paper by swinging the near flap to the right.



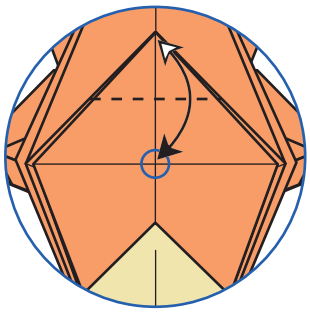
30. Squash-fold.



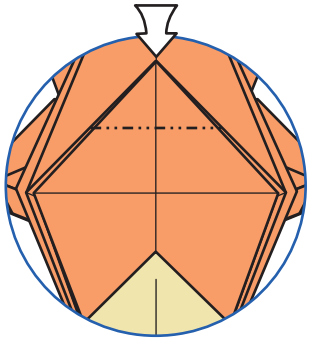
31. Reverse-fold using existing creases.



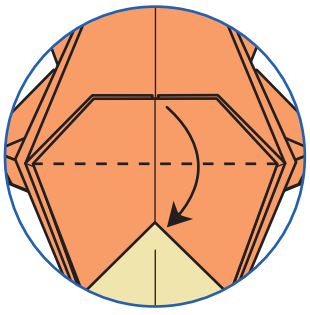
32. Fold and unfold.



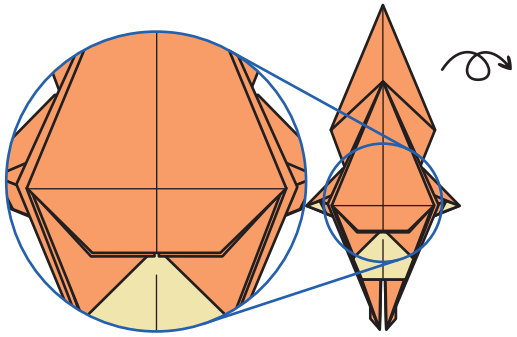
33. Fold and unfold.



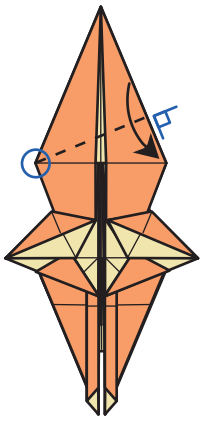
34. Open-sink.



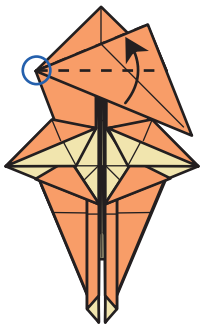
35. Fold the edges down.



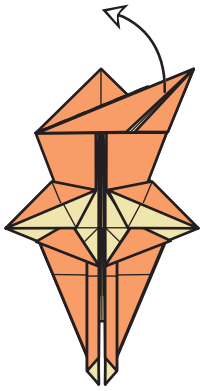
36. Turn the paper over.



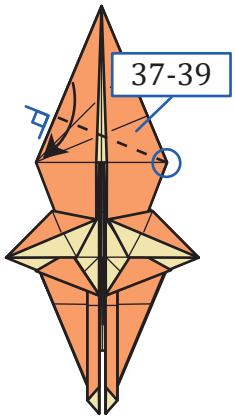
37. Fold the top-right edge onto itself using a fold-line which goes through the circled point.



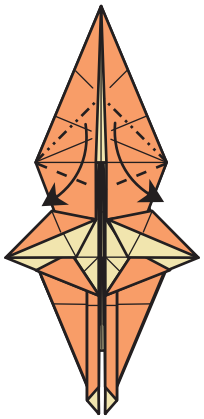
38. Fold the lower edge to the upper edge.



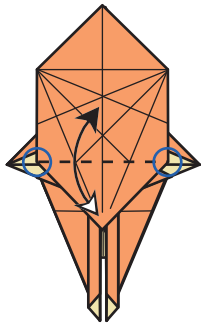
39. Unfold steps 37 and 38.



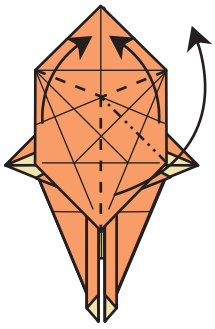
40. Repeat steps 37 to 39, flipping left and right.



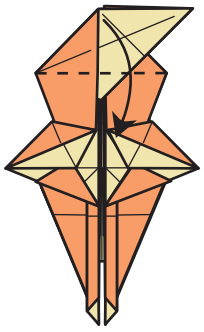
41. Pinch the mountain folds shown on the near layer only, and pull them in the direction shown until the paper is flat.



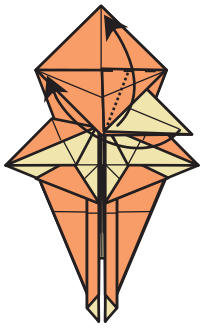
42. Fold and unfold the near layer only.



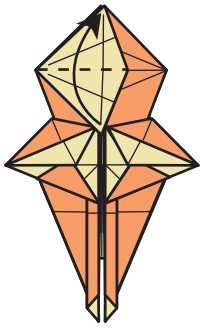
43. Rabbit-ear the raw corner up to the right.



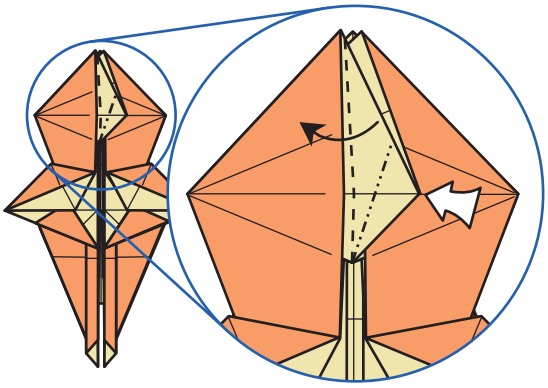
44. Fold the connected layers down.



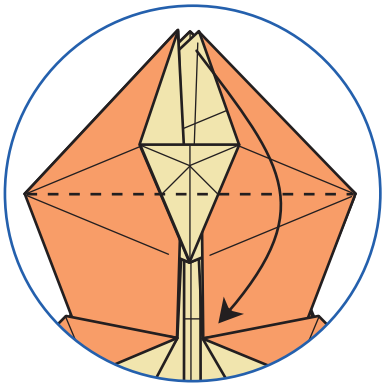
45. Fold the near corner up, and squash-fold the raw corner to the left.



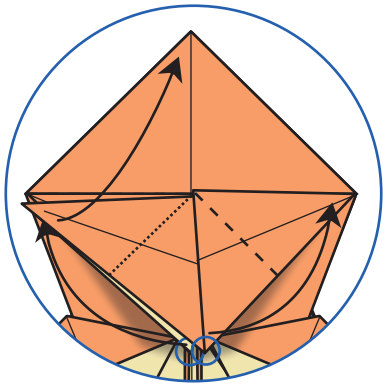
46. Fold one corner up.



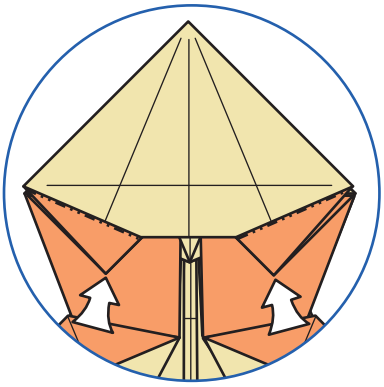
47. Spread-sink the corner.



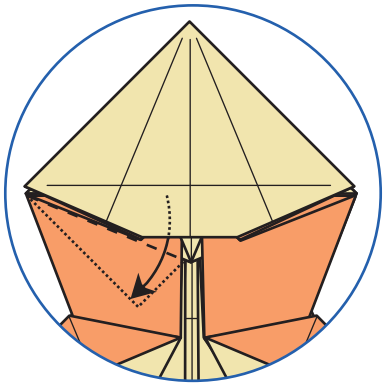
48. Fold the two corners down together.



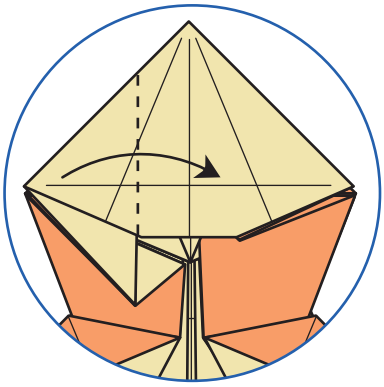
49. Fold the circled corners to the sides and flatten the raw corner upwards.



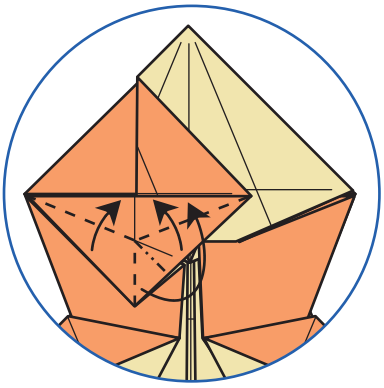
50. Reverse-fold the two corners up.



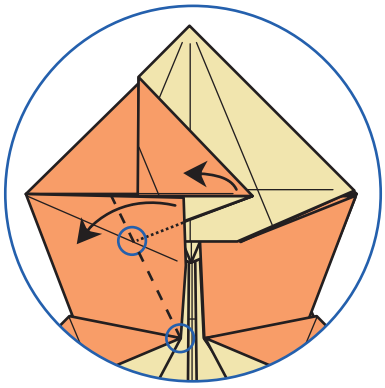
51. Carefully unfold the paper along the left raw edge; pull the hidden horizontal valley down and turn it into a mountain.



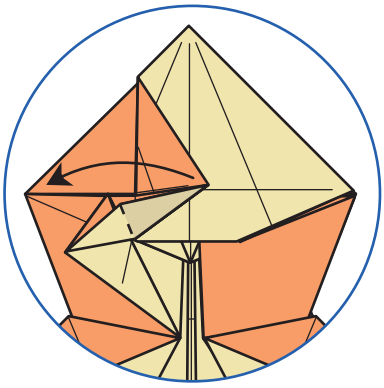
52. Fold the corner to the right.



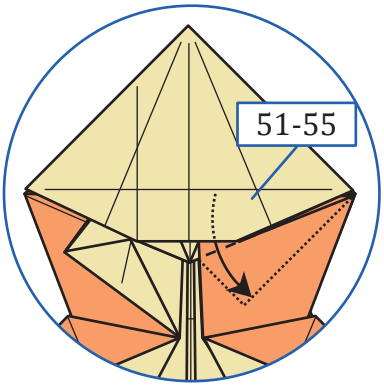
53. Rabbit-ear the corner up and to the right.



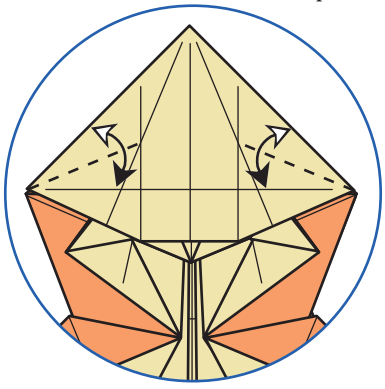
54. Make a new valley fold between the circled points. The connected corner will come forwards; the paper won't lie flat until after step 55.



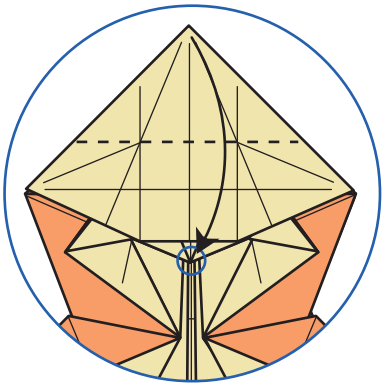
55. Flatten the corner to the left.



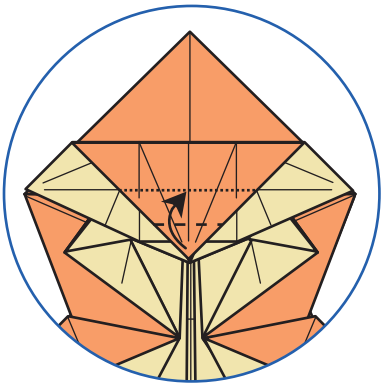
56. Repeat steps 51 to 55 on the right.



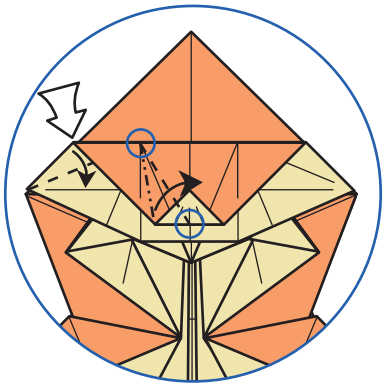
57. Fold and unfold two angle bisectors.



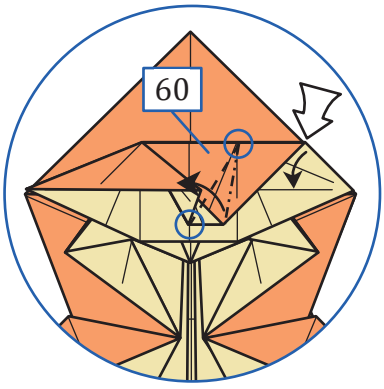
58. Fold the raw corner down to the circled point.



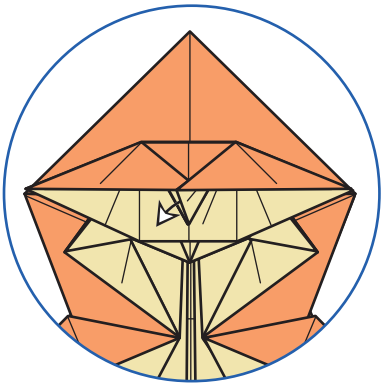
59. Fold the raw corner up so it is just above the level of the hidden crease.



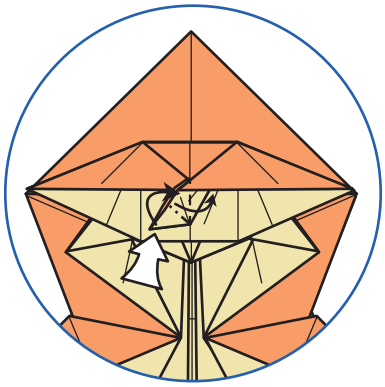
60. Make a new valley fold that connects the circled points, and swivel-fold the raw edge.



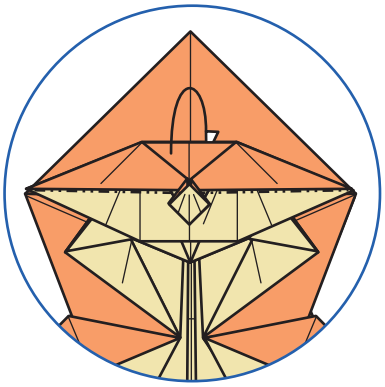
61. Repeat step 60 on the right.



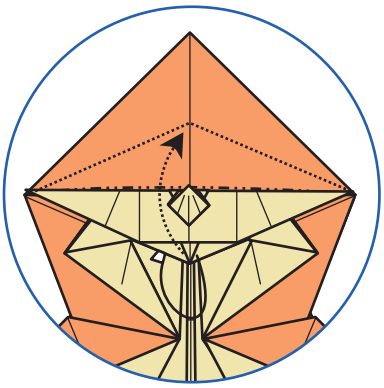
62. Pull out the raw corner.



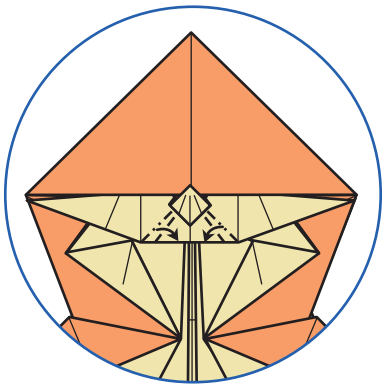
63. Squash-fold to form the nose.



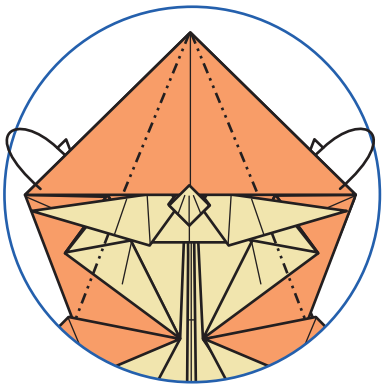
64. Mountain-fold the edge behind into the **nearest** of the two pockets.



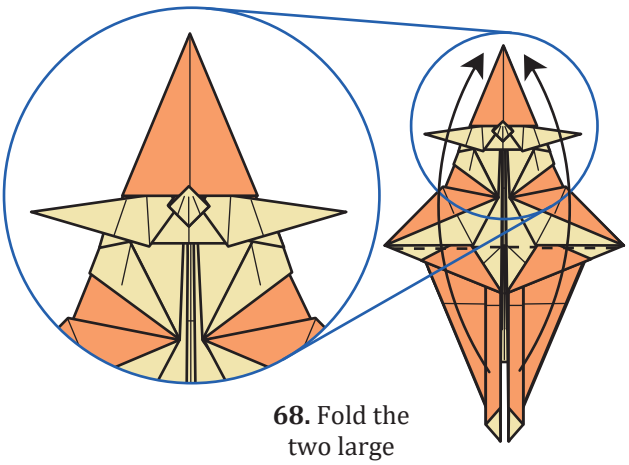
65. Open the paper a little and mountain-fold one flap up inside the paper so that it goes underneath the coloured triangle at the top.



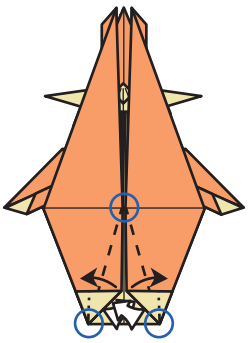
66. Gently pleat the near layers of paper to suggest the centre part of a moustache. The nose will pop outwards towards you slightly.



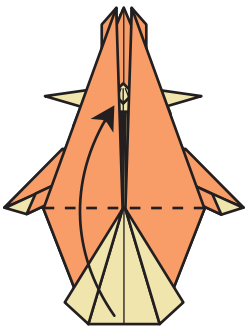
67. Mountain-fold the edges behind.



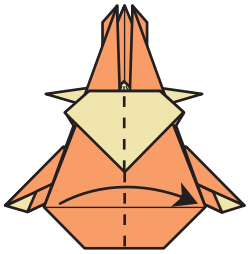
68. Fold the two large flaps up.



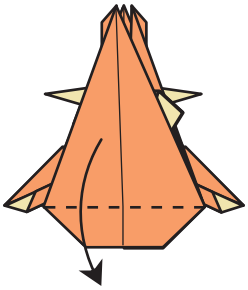
69. Swivel-fold the raw edges to the sides, making new valley folds between the circled points.



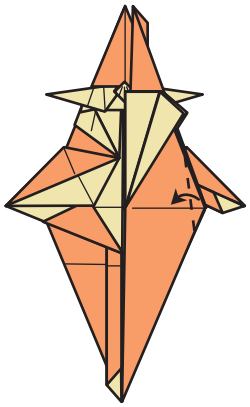
70. Fold one flap up.



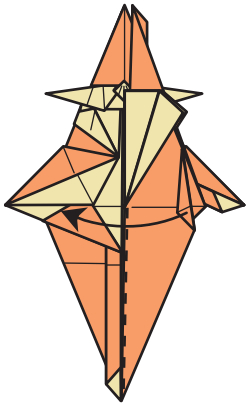
71. Fold one flap to the right.



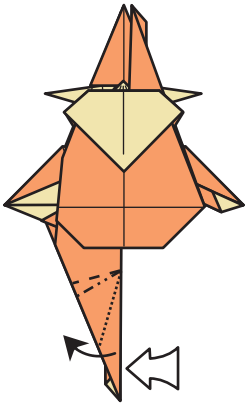
72. Fold one flap down.



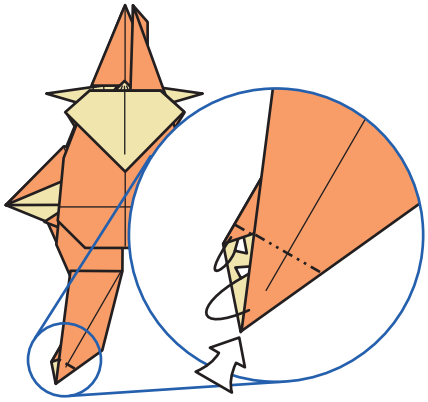
73. Fold one corner across.



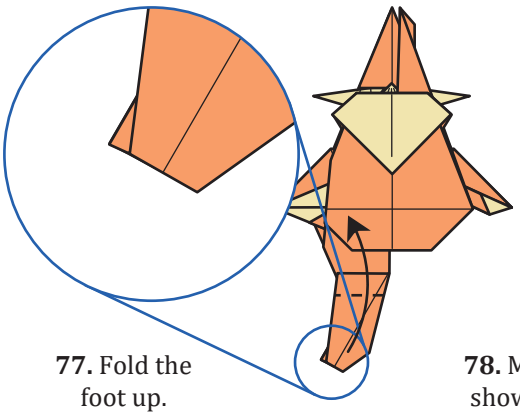
74. Fold one flap to the left.



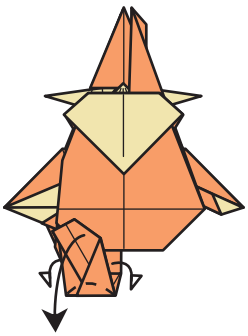
75. Swivel-fold the edge to the left using new fold-lines. The mountain fold should end up horizontal.



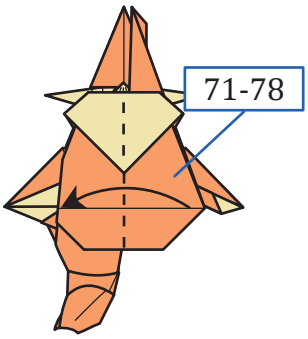
76. Reverse-fold the tip. (Optionally, you can get a strong lock by also reverse-folding the white triangle underneath the raw edge, as shown).



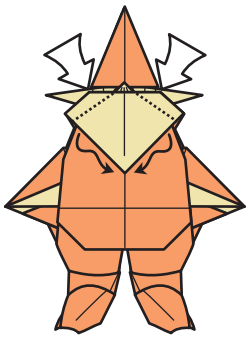
77. Fold the foot up.



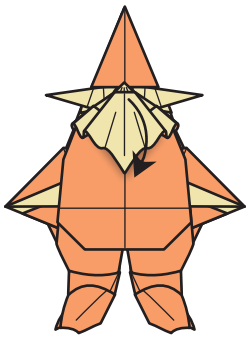
78. Make a curved valley fold where shown, and curl the sides of the leg behind. The foot will end up perpendicular to the rest of the paper.



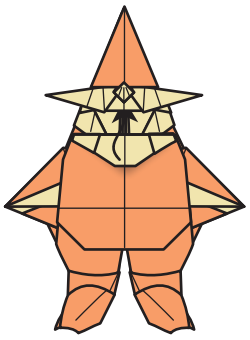
79. Repeat steps 71 to 78 on the right.



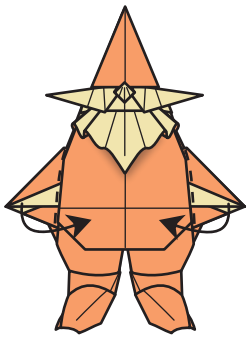
80. Closed-sink the white corners, but don't flatten the paper on the near layer: instead let the raw edge ripple. The paper won't lie flat from now on.



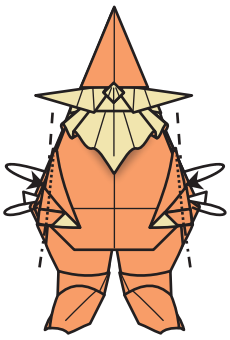
81. Gently lift the top of the beard forwards.



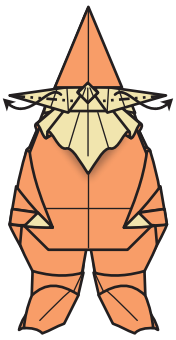
82. Tuck the top of the beard under the moustache.



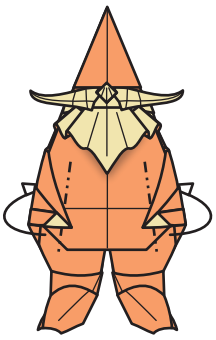
83. Fold the arms across.



84. On each side, mountain-fold the near corner and valley-fold the far corner, so they both go between the two layers.



85. Curl the tips of the moustache.



86. Curl and shape the whole body.

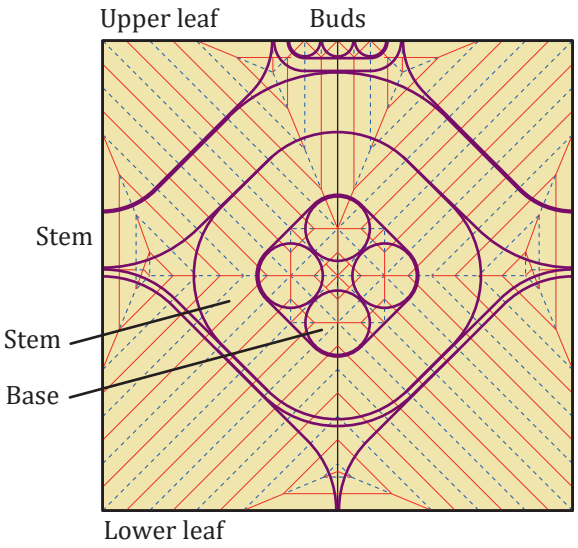
Nettle

Designed for Esther Wang

First time: 30cm/12''

Paper preferences:
- Thin
- Shapeable

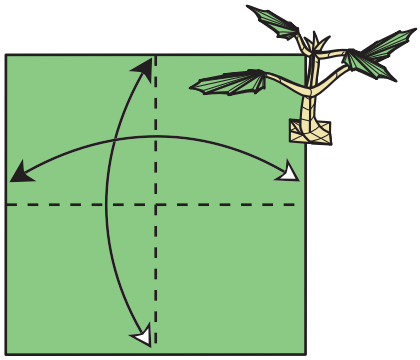
Recommended papers:
- Double tissue
- Foil-backed paper



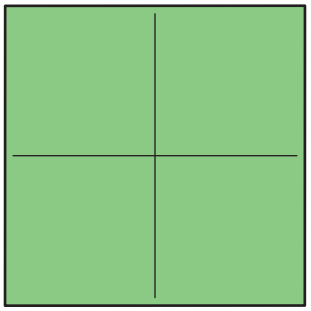
The main distinguishing feature of an origami nettle is its jagged leaves (unless you want to add barbs to the paper, which might make folding rather uncomfortable).

You could just as easily (slightly easier, in fact) skip steps 77 and 78 to get rounder leaves if you prefer to make a generic plant.

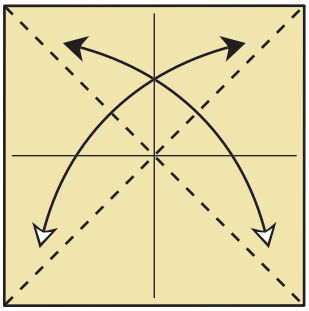
Start leaf colour side up.



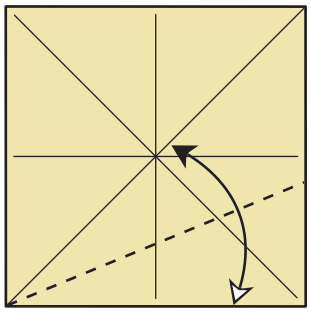
1. Fold and unfold the vertical and horizontal lines.



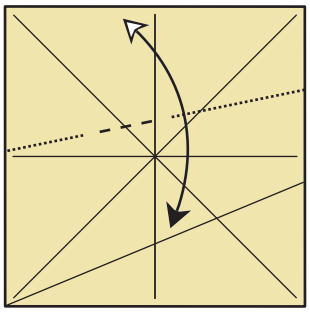
2. Turn the paper over.



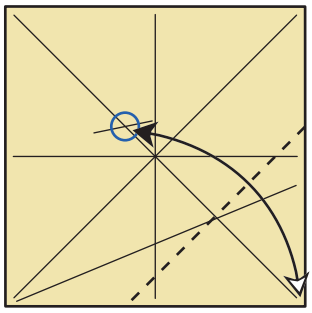
3. Fold and unfold the diagonals.



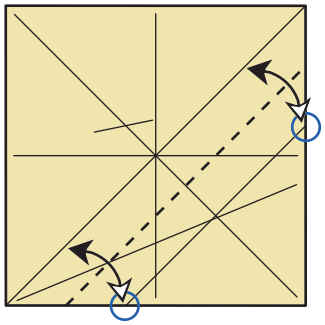
4. Fold an angle bisector, but only mark the paper gently, then unfold.



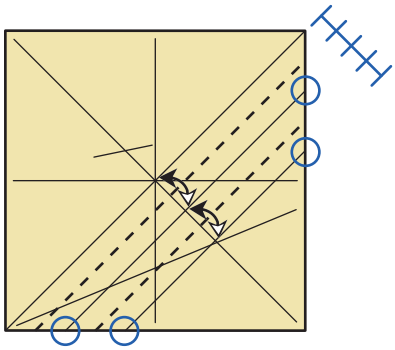
5. Fold the top raw edge to the crease you just made, but only mark firmly where the fold-line crosses the downward diagonal, then unfold.



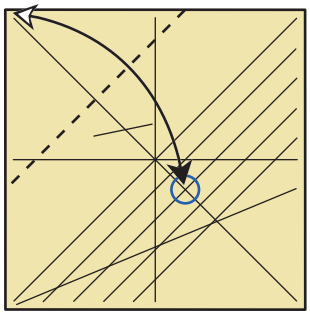
6. Fold the bottom-right raw corner to the circled point, then unfold.



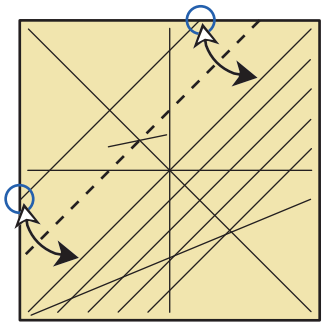
7. Fold the crease you just made onto the diagonal, then unfold.



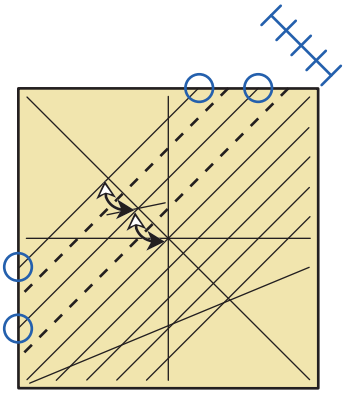
8. Fold and unfold halfway between the indicated creases.



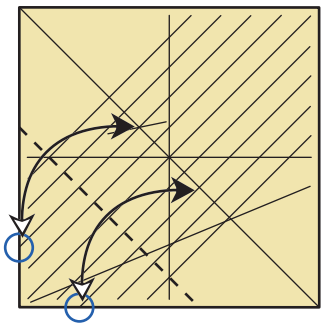
9. Fold the top left raw corner to the circled point, then unfold.



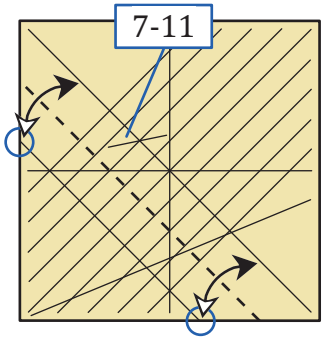
10. Fold the crease you just made onto the diagonal, then unfold.



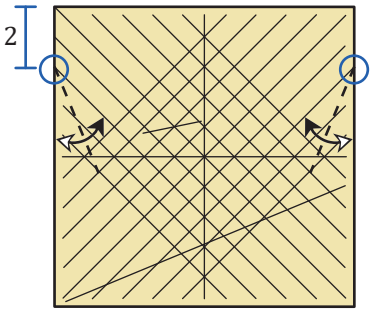
11. Fold and unfold halfway between the indicated creases.



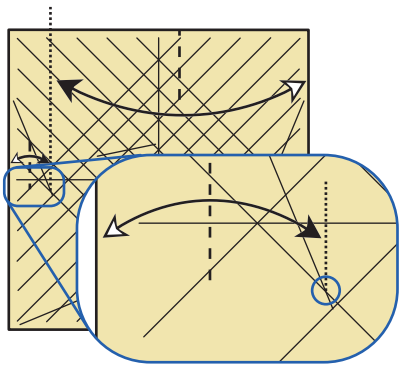
12. Fold the circled points to the diagonal, then unfold.



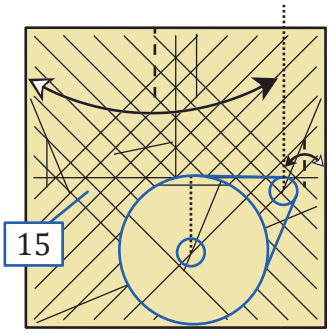
13. Repeat steps 7 to 11 flipping left and right.



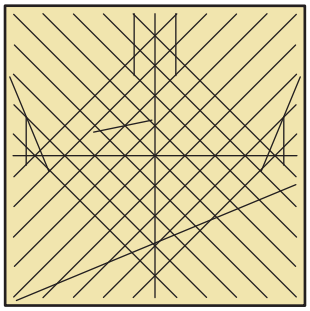
14. Fold and unfold two angle bisectors, only marking firmly where shown.



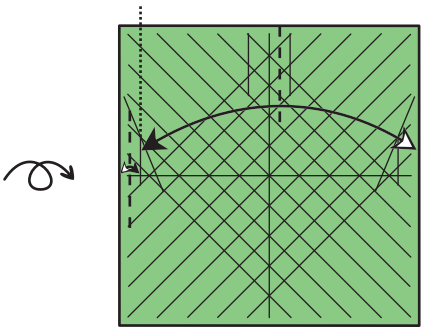
15. Fold and unfold two vertical lines by bringing the raw edges to the circled point (the intersection of creases from steps 12 and 14). Mark firmly only in the regions shown.



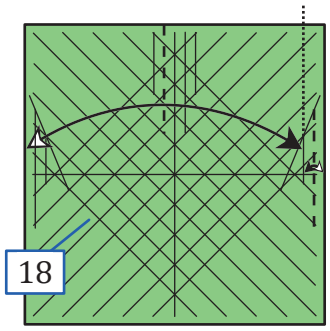
16. Repeat step 15 flipping left and right: fold and unfold the left and right raw edges to the intersection of creases from steps 6 and 14, marking firmly only in the regions shown.



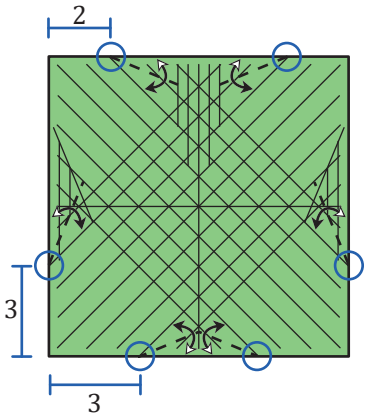
17. Some creases will no longer be shown. Turn the paper over.



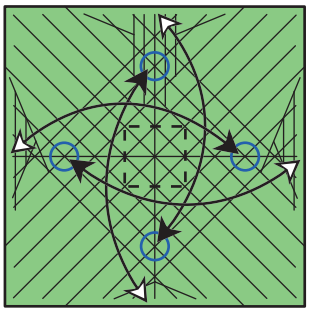
18. Fold and unfold the left and right raw edges to the vertical crease, only marking firmly in the regions shown.



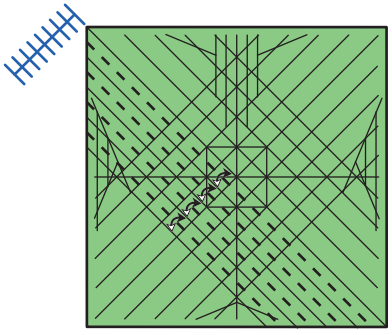
19. Repeat step 18 flipping left and right: fold and unfold the left and right raw edges to the vertical crease only marking firmly in the regions shown.



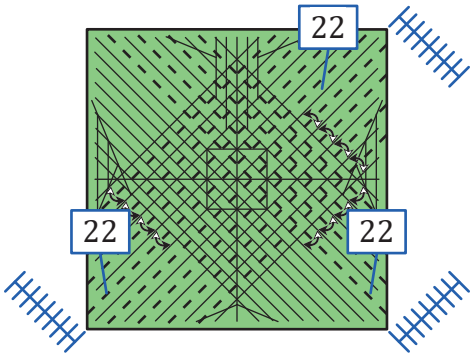
20. Fold and unfold six angle bisectors in the regions shown.



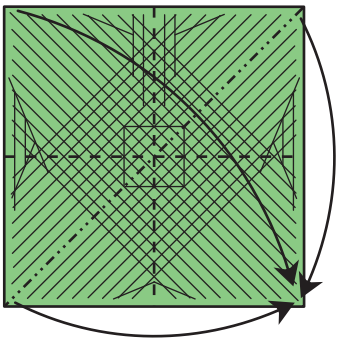
21. Fold and unfold a square in the centre of the paper by folding each raw edge to the opposite circled point, as shown.



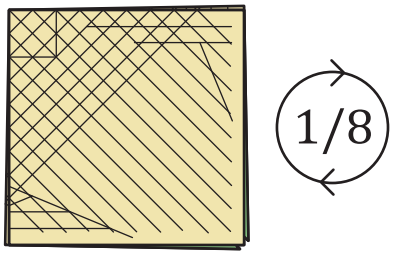
22. Fold and unfold halfway between the indicated creases. You may find it easiest to pleat these.



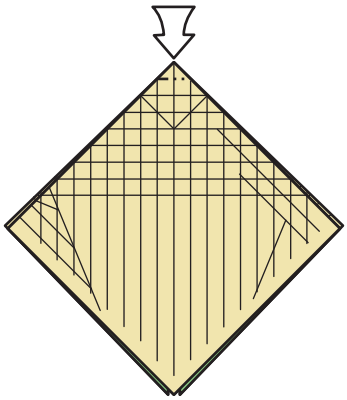
23. Repeat step 22 on the other three corners.



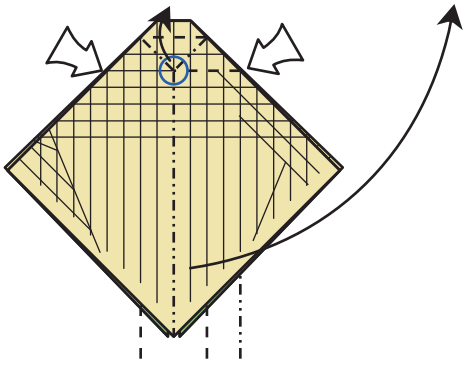
24. Make a preliminary base by bringing all of the raw corners to the bottom right.



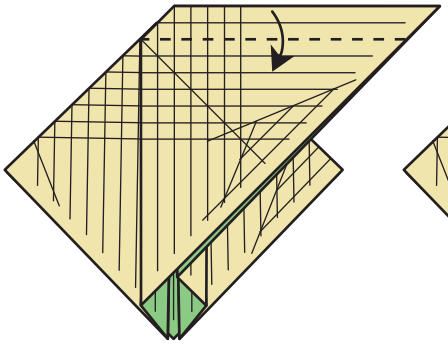
25. Rotate the paper ⅛ of a turn clockwise.



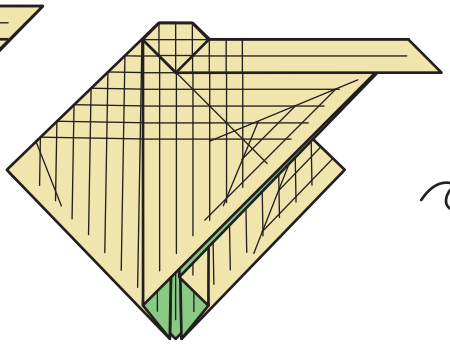
26. Open-sink the small corner at the top of the paper.



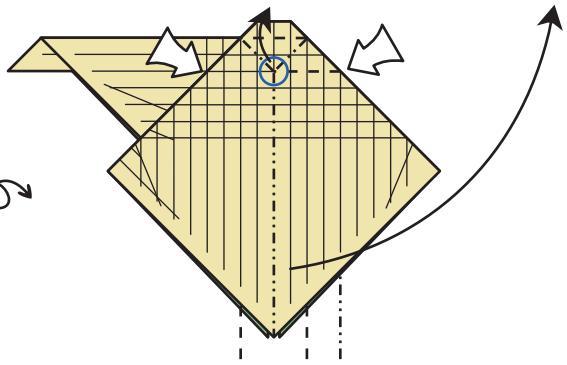
27. Bring the circled point upwards and flatten the paper by swinging the paper at the front to the right.



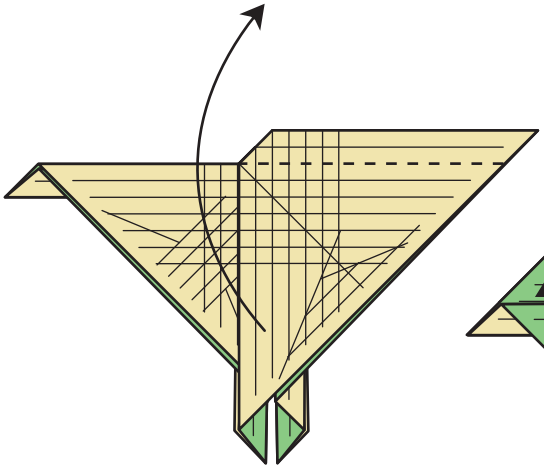
28. Fold the edge down.



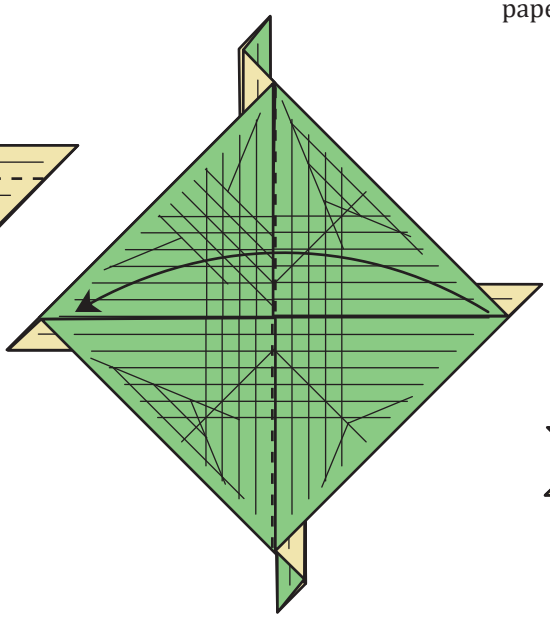
29. Turn the paper over.



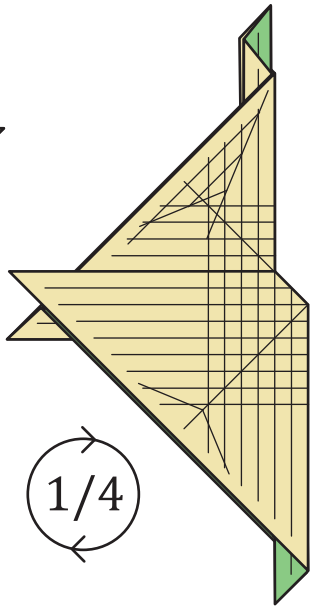
30. Bring the circled point upwards and flatten the paper by swinging the paper at the front to the right.



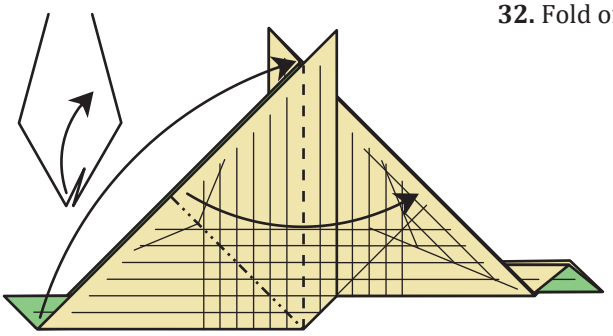
31. Fold one large flap up.



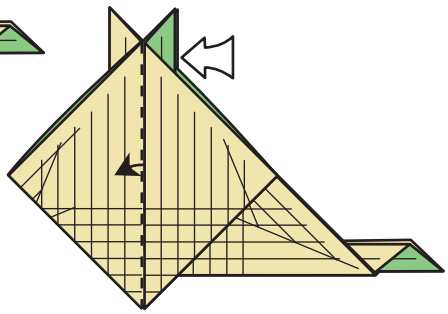
32. Fold one large flap to the left.



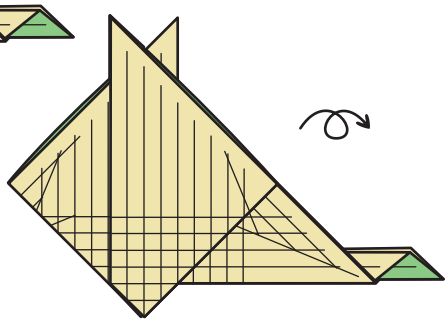
33. Rotate the paper ¼ of a turn clockwise.



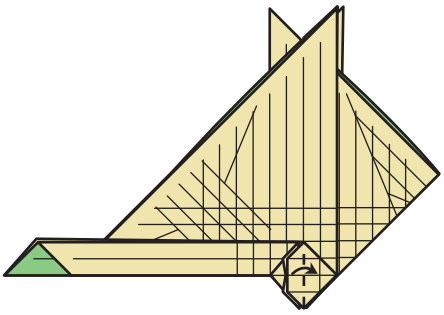
34. Squash-fold using existing creases. The inner edge goes on the right.



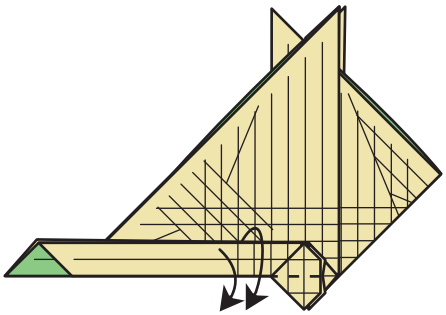
35. Unsink the edge to the left.



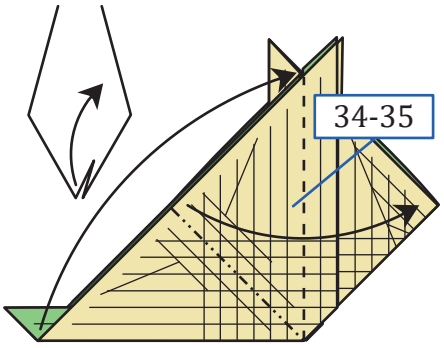
36. Turn the paper over.



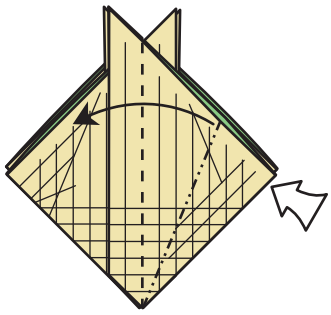
37. Fold the small connected edges to the right.



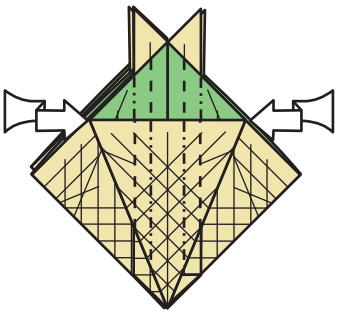
38. Fold the two edges down.



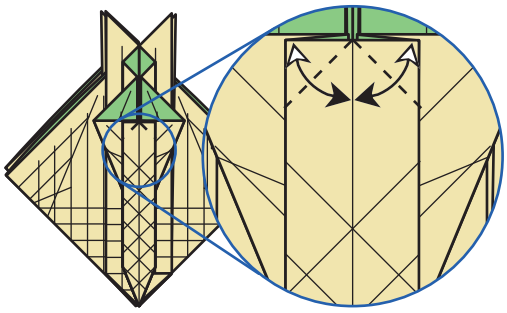
39. Repeat steps 34 and 35.



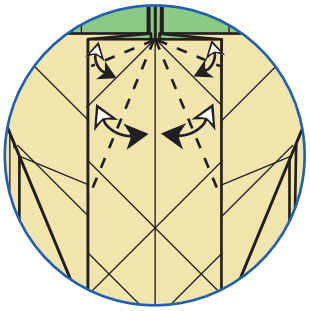
40. There should be two creases parallel to the edge on the bottom right (but if not, rearrange your flaps so that this is the case). Squash-fold the edge.



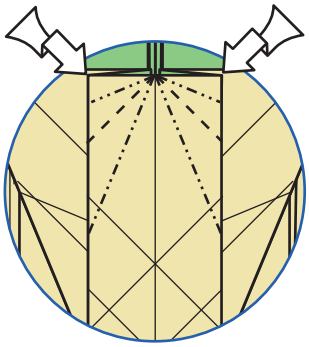
41. Reverse-fold both sides in and out using existing creases.



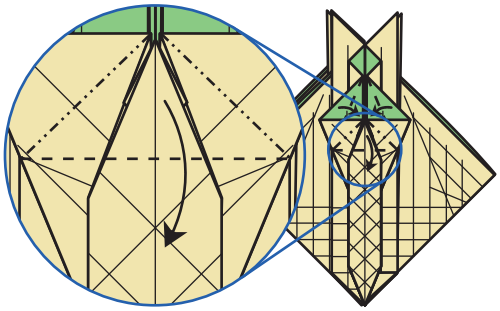
42. Fold two angle bisectors and unfold.



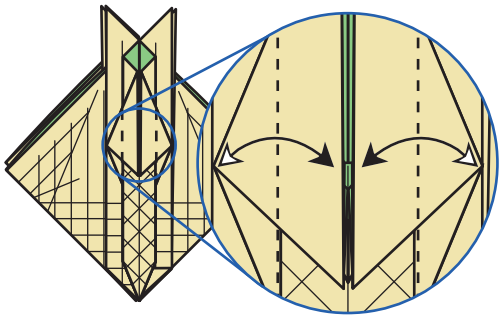
43. Fold and unfold four angle bisectors.



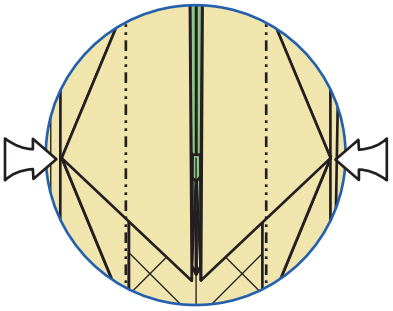
44. Reverse-fold in and out using creases from steps 42 and 43.



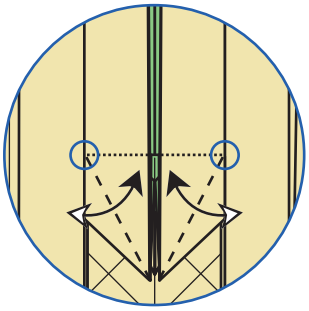
45. Petal-fold the corners down together.



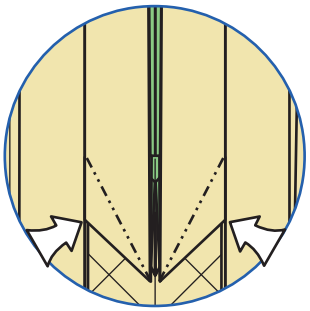
46. Fold and unfold to transfer a crease to the near layers.



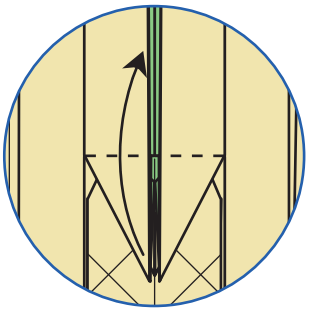
47. Open-sink on each side.



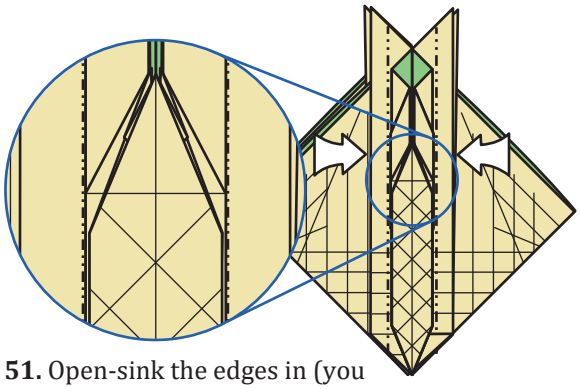
48. Fold and unfold.



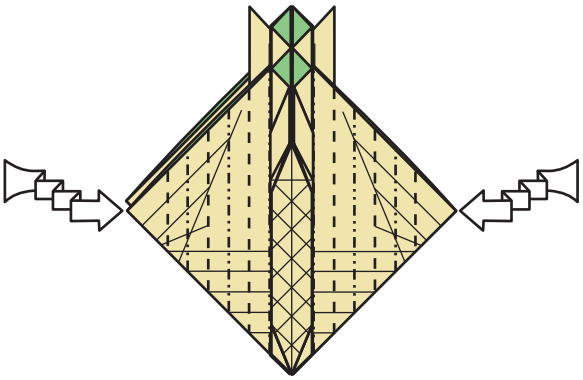
49. Open-sink using the creases you just made.



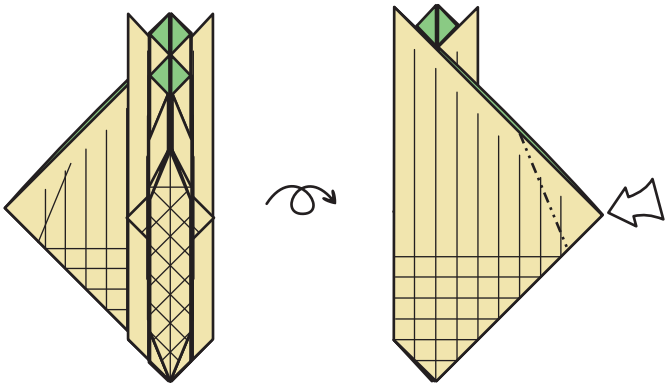
50. Fold the corners up.



51. Open-sink the edges in (you may prefer to spread-sink then open the layers).

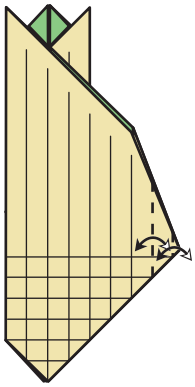


52. Reverse-fold the corners in and out using six existing creases on each side.

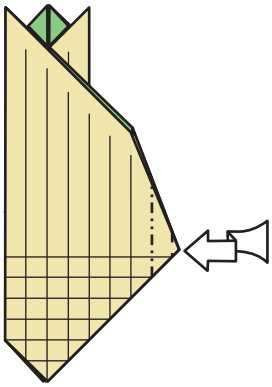


53. Turn the paper over.

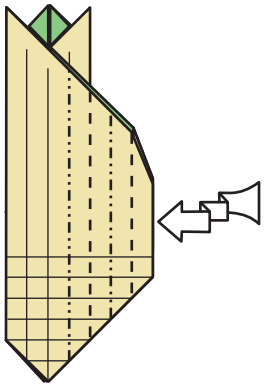
54. Reverse-fold.



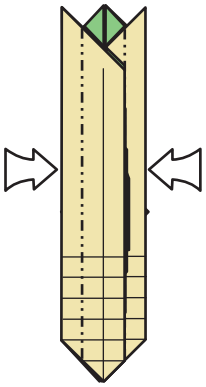
55. Fold and unfold to transfer the vertical creases to the middle layers.



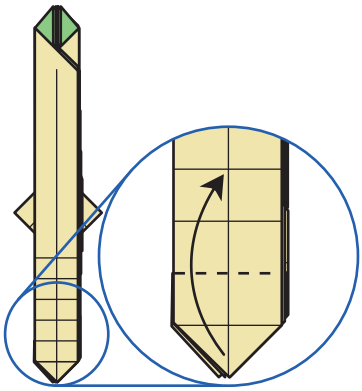
56. Open-sink in and out using the creases you just made.



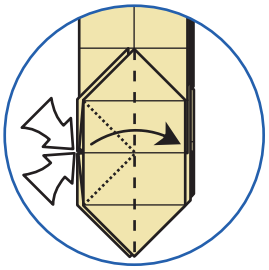
57. Reverse-fold in and out using existing creases.



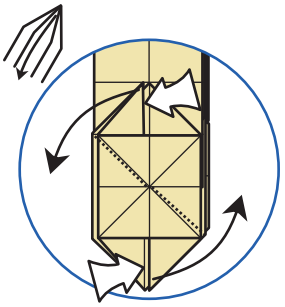
58. Open-sink the edges in (you may prefer to spread-sink, then open the layers).



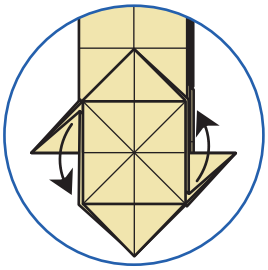
59. Fold the nearest connected set of flaps upwards.



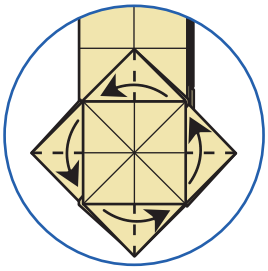
60. Fold one edge to the right, then flatten the square.



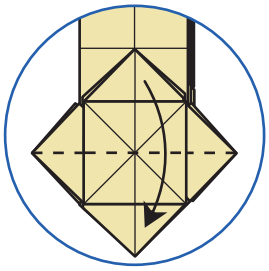
61. Reverse-fold two corners: divide the layers evenly so there are two edges on both sides of each spine.



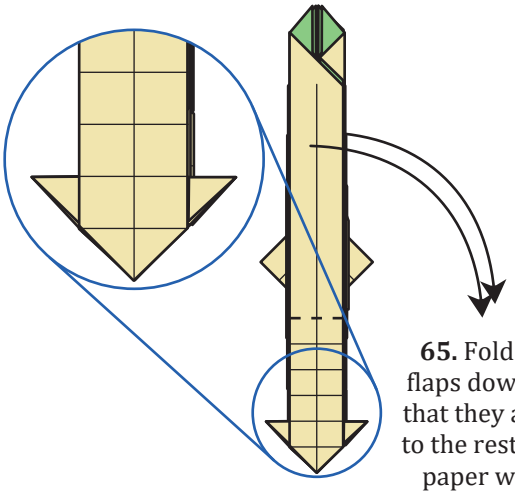
62. Fold one layer anticlockwise on the left and right.



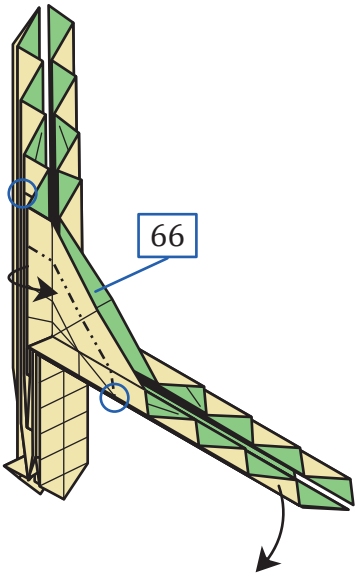
63. Twist the central square anticlockwise.



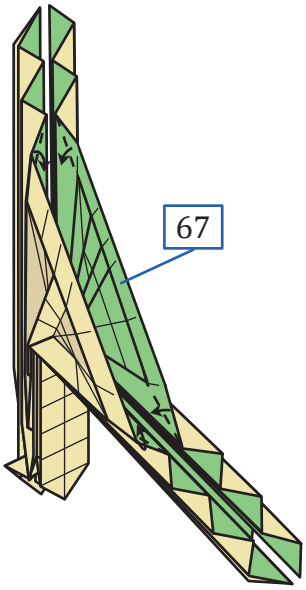
64. Fold the top corner down.



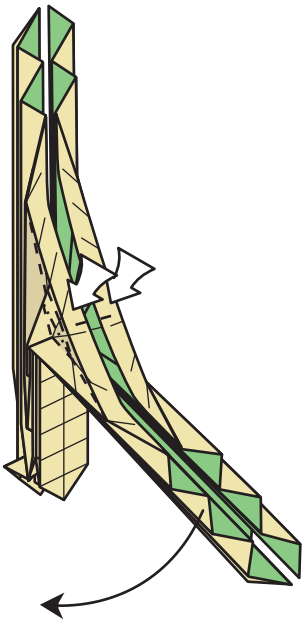
65. Fold the nearest two flaps down towards you so that they are perpendicular to the rest of the paper. The paper won't lie flat until after step 68.



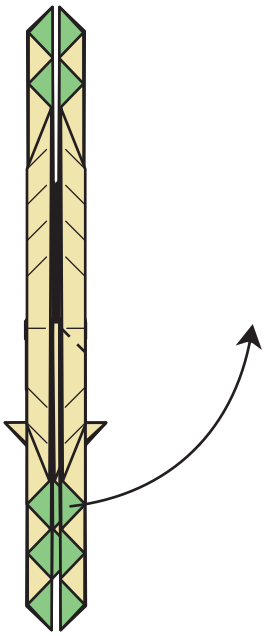
66. Spread the layers of the nearest pleat on the vertical flaps to straighten the mountain fold that connects the circled points. Repeat on the right.



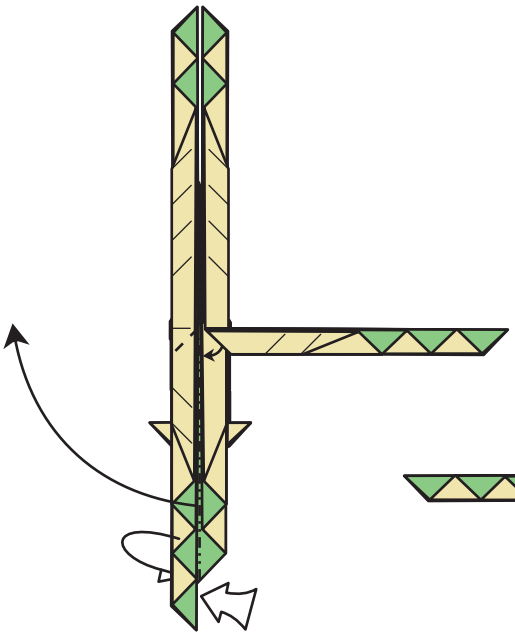
67. Fold the raw edge into the centre using both the mountain fold you just spread out and the existing angle bisectors at either end of the mountain fold. Repeat on the right.



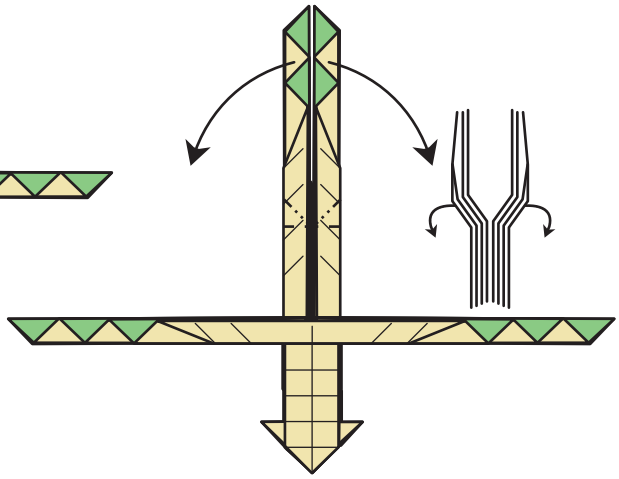
68. Collapse the pleats down and fold the near flaps all the way down to lie flat. This should happen neatly using the existing creases, as shown here (but neatness isn't critical).



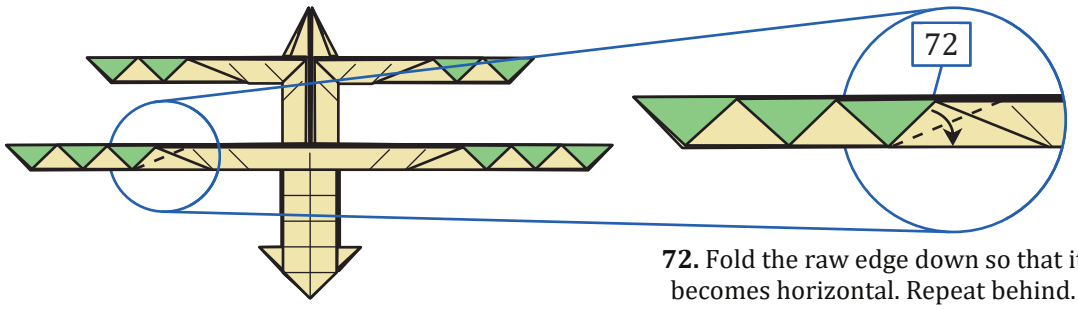
69. Fold the bottom-right flap to the right.



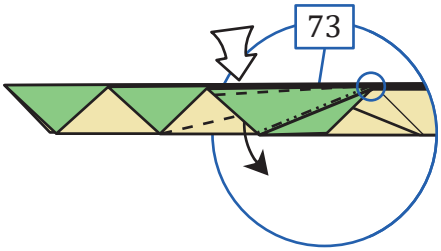
70. Fold the other flap in half and swivel-fold it to the left.



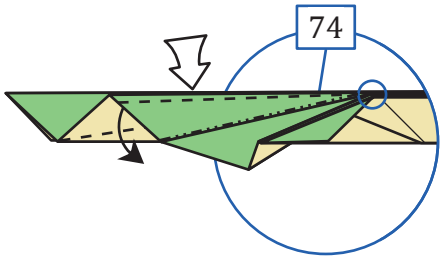
71. Pleat the two upper flaps to the sides.



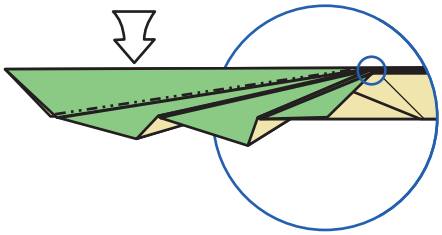
72. Fold the raw edge down so that it becomes horizontal. Repeat behind.



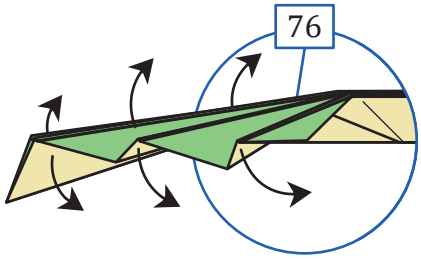
73. Reverse-fold one edge down. Repeat behind.



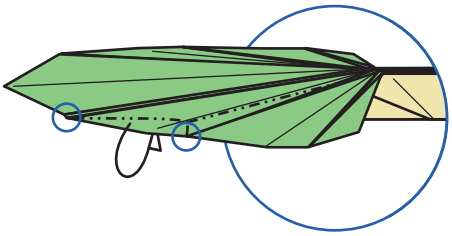
74. Reverse-fold another edge down. Repeat behind.



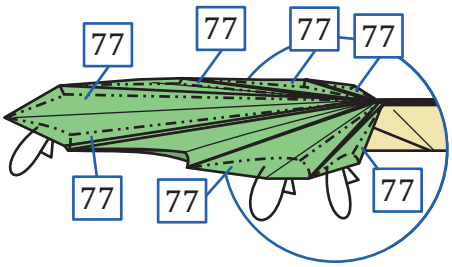
75. Reverse-fold the raw corner down.



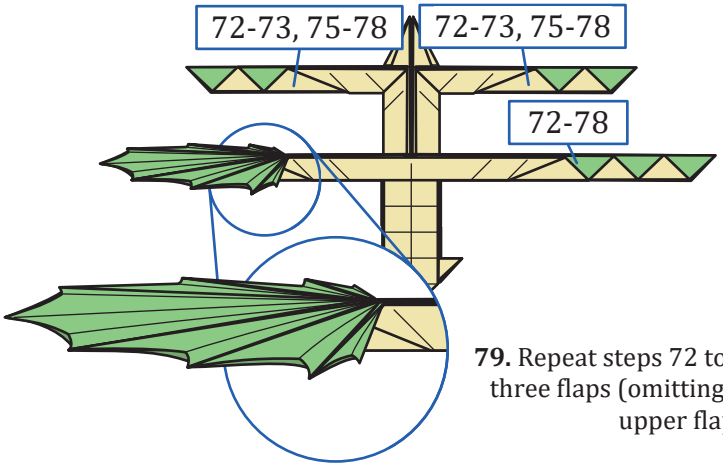
76. Spread the layers flat. Repeat behind.



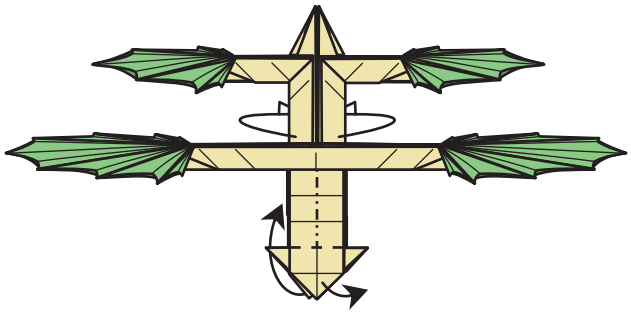
77. Use a curved mountain fold to sharpen the paper at the circled points.



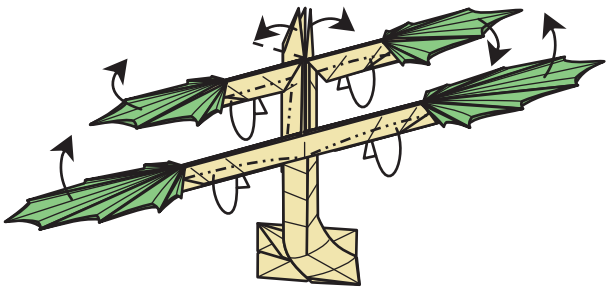
78. Repeat step 77 to make the whole leaf spiky.



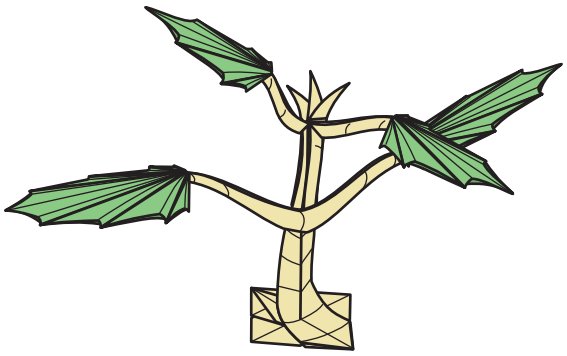
79. Repeat steps 72 to 78 on the other three flaps (omitting step 74 on the upper flaps).



80. Open the square base at the bottom and carefully mountain-fold the whole model in half.



81. Spread the corners at the top, pinch the stems in half, and shape the model as you wish.

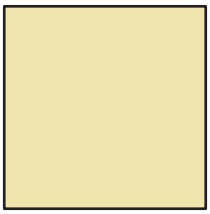


A botanical drought

Flowers are some of the most popular origami models, and for many reasons. They are (usually) symmetrical, which makes them easy to design and fold, they are easy to identify as a flower (even if no actual species is depicted), and they are colourful and attractive. But there are relatively few origami flowers that also include the rest of the plant from the same sheet.

'Complete' origami plants are scarce for the exact opposite reasons as to why flowers are common. They are wild and typically asymmetric, often nondescript, and invariably come in unexciting shades of green. But I'm going to explore a deeper, origami-specific reason for this lack of origami plants.

What shape is a square?



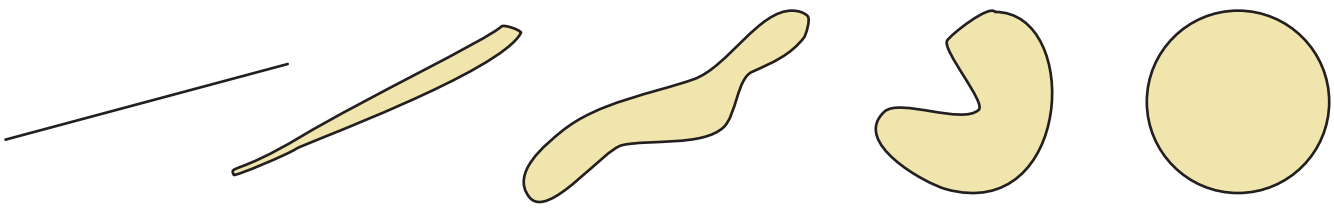
A square (if you'll believe it).

That might sound like a stupid question, and perhaps stupider still when it's posed to origami enthusiasts who, of all groups of people, are some of the most acquainted with squares.

But I'm not looking for a technical answer involving right angles, parallel lines, or side lengths. I'm taking a step back and squinting at a square from a distance. From a worse vantage point, we lose the details and find perhaps the most fundamental property of all – it's a lump. This kind of imprecise property is useful to talk about because it holds for lots of other shapes besides squares, including circles, regular polygons, and the rectangle shown above (the above shape is not a square because it is a few pixels too narrow, which demonstrates that being too precise about things can be very annoying and get in the way of observing more fundamental properties).

Lines and lumps

Lines are one-dimensional, whereas areas are two-dimensional. We might like to define lumpiness by thinking of a spectrum, where moving from lines to areas means increasing the dimension. This is far from rigorous mathematics but I hope you can forgive my woolliness. (In fact, this sort of idea has plenty of credence – fractional dimensions are an established concept and very useful for talking about fractals). Just think of the extent to which a shape is **linish** or **lumpy** using the images below.



From left to right, these shapes becomes increasingly lumpy (less linish).

What shapes are easy to fold?

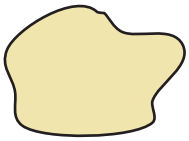
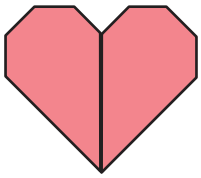
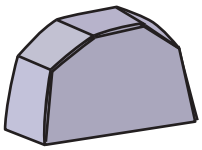
Lumps, in short. After all, we begin with a square, which is already a lump. The simplest traditional origami bases are normally quite lumpy too. Lines are not hard to fold either – just fold the paper in half in the same direction several times to narrow it arbitrarily. What gets tricky is combining multiple lumps and lines together.

Abstracting subjects

In tree theory, subjects are approximated by stick figures (or more – see the *Behind the Design* chapter for Psyche on page 60). But rather than starting with a subject, we're going to briefly think about various configurations of lumps and lines. I'll attempt to put these in difficulty order, which is tricky. You may disagree with my subjective ordering, which is, of course, completely fine.

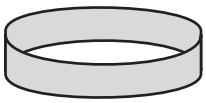
Single-lump

Single-lump models have one lump and no lines. The lump might have some indentations (but these disappear when squinting).

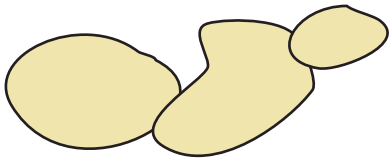
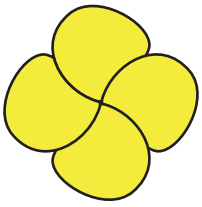
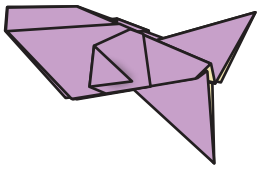
Single-line

Single-line models have one line and no lumps and are normally harder to fold than single-lump models.



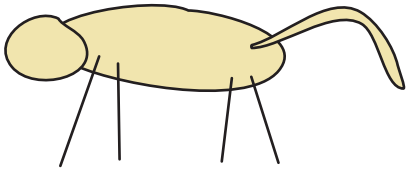
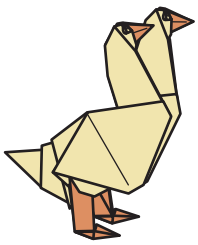
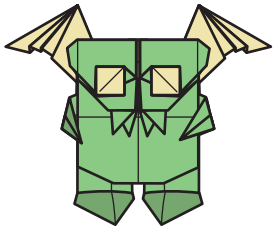
Multi-lump

Multiple lumps combined together can be hard to distinguish from the single-lump case. As mentioned, this is an extremely general categorisation, so don't worry about the exact boundaries here. Flowers and fish often fall into this category.

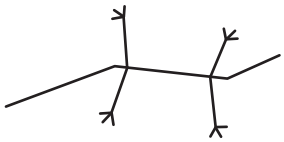
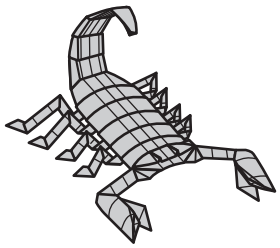
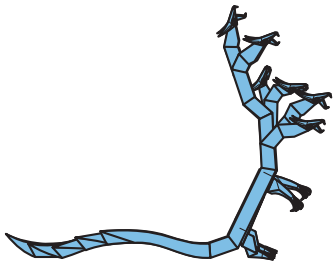
Lump with lines

One or more lumps at the centre, with one or more lines coming from the lump clump. This is the typical form for mammals and birds.

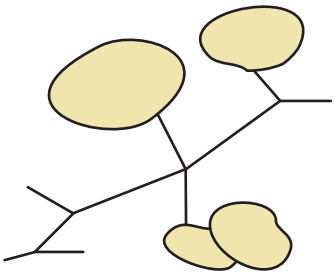
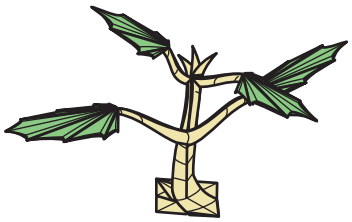
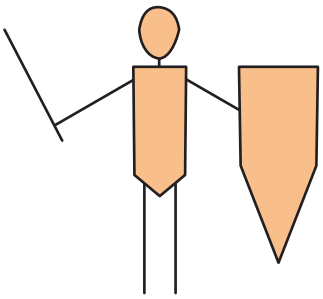
Tree

These multi-line forms are spindly and arise naturally from the stick figures found in tree theory. These models are characterised by lots of sinks and are common for insects and reptiles.

Tree with lumps

In nature, these forms appear predominantly in plants. Other cases are often multi-subject figures (e.g. a human holding a shield).

This final category is tricky (within purist origami design) because of the way features have to be arranged within the square. There's more paper between features and less at the extremities, so normally it makes perfect sense for lumps to form in the middle of a model and for flaps to taper towards their ends. You can resist this tendency somewhat by narrowing the paper in the middle with sinks, as happens with many designs in the tree category above. But even if they look uniformly thin, if you fold one, you'll feel that there are still many more layers of paper in the centre (and sometimes this is still visible).

To defy this natural tendency completely is a lot harder. It involves making a thin bridge between two lumpy regions, which is the exact opposite of how the paper wants to be. Even apparently simple cases take a lot of work to design and fold, such as the Nettle with only four leaves. This is, perhaps, the main reason why plants are so infrequently designed.

You could extend the line/lump system above by adding another category with more line and lump configurations, but this wouldn't make an intrinsically harder category because the biggest difficulty hurdle has already been crossed.

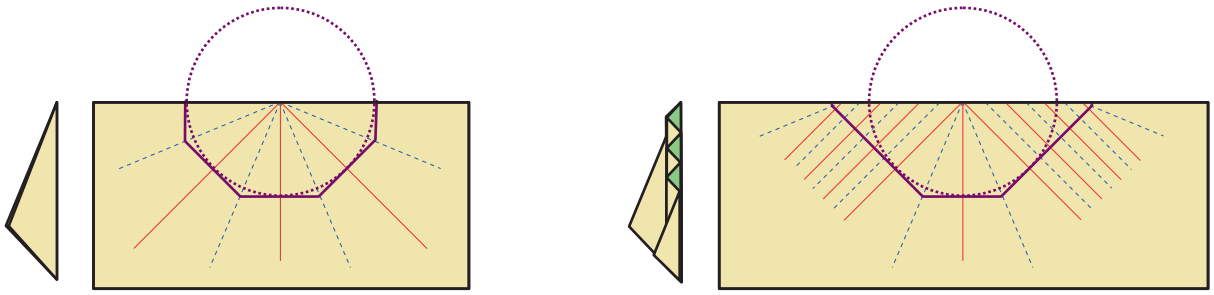
How do we design plants then?

We shouldn't necessarily avoid an approach just because it's going to result in a tricky model, but we do need to take the difficulty into account so that we can mitigate any potential pain. In the case of a Nettle, this means we'll want to severely limit the number of leaves we have to make.

Leaves

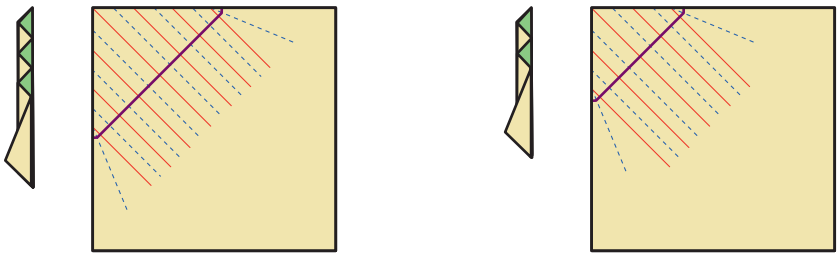
Regular (leaf node) flaps typically end in a point. For example, a typical 22.5° edge flap is shown on the left below. As this is a 22.5° flap, the actual paper used is an octagon. The octagon here is perpendicular to the raw edge where they intersect (along hinge creases). This allows adjacent flaps to be placed as close as possible along the raw edge. This uses space efficiently, but doesn't leave any excess paper which can be spread out to make the flap wider.

Instead, we'll use a larger shape that isn't perpendicular to the raw edge, as shown on the right below. The wide region along the raw edge zigzags up and down and can be opened out to make a leaf.



Left: A normal 22.5° edge flap. Right: A wider flap with pleats that can be spread out.

There are other similar shapes we could use, but this is one of the simplest structures that uses 22.5°. One key advantage of this is that we can adapt it to a corner flap and the pleats still look the same. We can also adjust this shape by changing the number of pleats to make bigger or smaller leaves.



Left: A pleated flap at the raw corner. Right: A smaller flap made with fewer pleats.

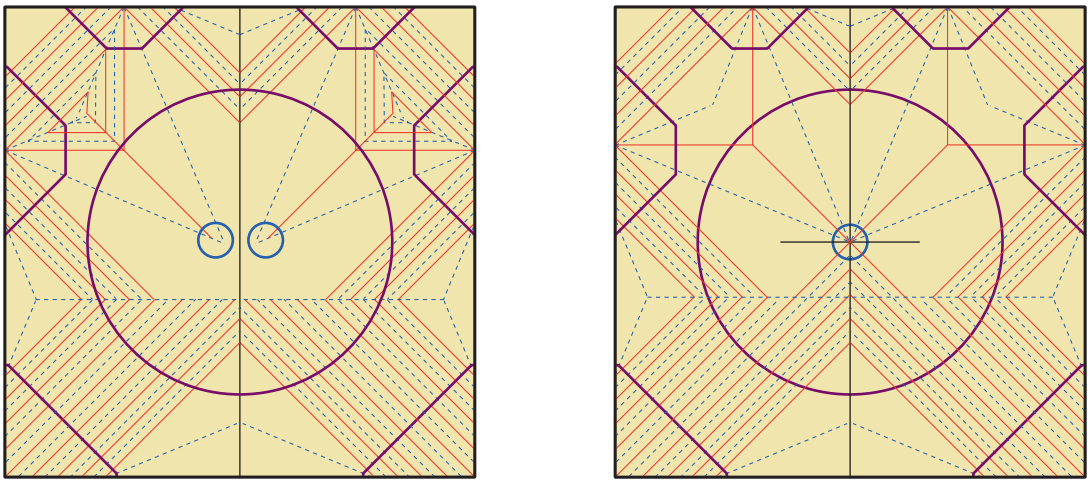
To keep things simple, let's not consider any leaves made from the middle of the square. Instead, we'll allot all remaining paper in the middle of the square for a stem.

An arrangement

Now we need to fit some of these leaves around the perimeter of the square. A good rule of thumb is that if we have multiple flaps of a similar size, then we should aim to fit between six and eight edge or corner flaps around one central flap. So this gives between six and eight leaves around one stem. Eight leaves is a very small number for a plant, but we have to work with what the paper allows. In fact, given the extra width of the leaf flaps above, we should err on the conservative side here because we will likely only have room for six leaves.

Leaves tend to come in pairs, so we'll decide to make a symmetric arrangement. The leaves also get smaller towards the top of the plant, so we'll try to have one large pair in the lower half of the paper, and two smaller pairs in the top half. We can find an arrangement that works with these conditions; this is on the left below. As always, this isn't intended to be an exact crease pattern at this stage (it doesn't remotely fold flat), but it shows roughly where our flaps might go.

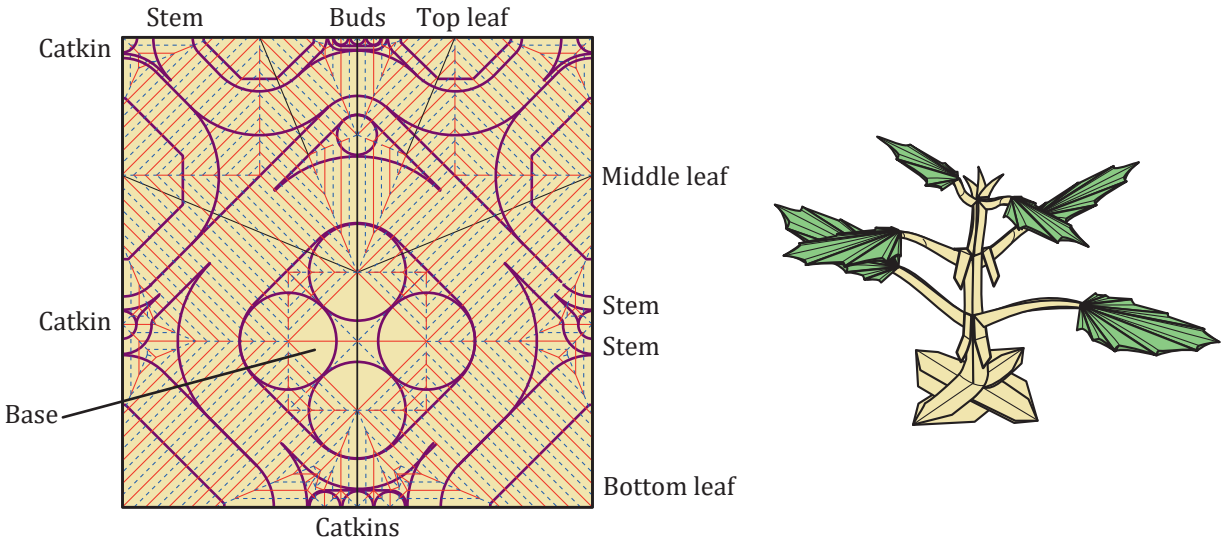
The primary problem with this arrangement is that a number of creases don't quite meet up nicely. These are circled in the image on the left. These are all very close to the centre of the paper, so we can fix this by forcing these creases to all come from the exact centre and seeing what this gives us. This central point provides a pleasant reference point too.



Left: An initial arrangement. Right: The creases are aligned to the centre of the square.

The creases on the perimeter all work, but if you try to fold the pattern above, it's a mess in the centre where the stem is. One issue is that the stem needs to be further from the small leaves at the top than the large leaves at the bottom, so we need to move the stem down. If we can get a larger flat region instead of a tip, that will allow the model to stand up. (The issue of how an origami plant balances is yet another thing that makes designing them difficult, and the solution here is also a lump at the end of a line.)

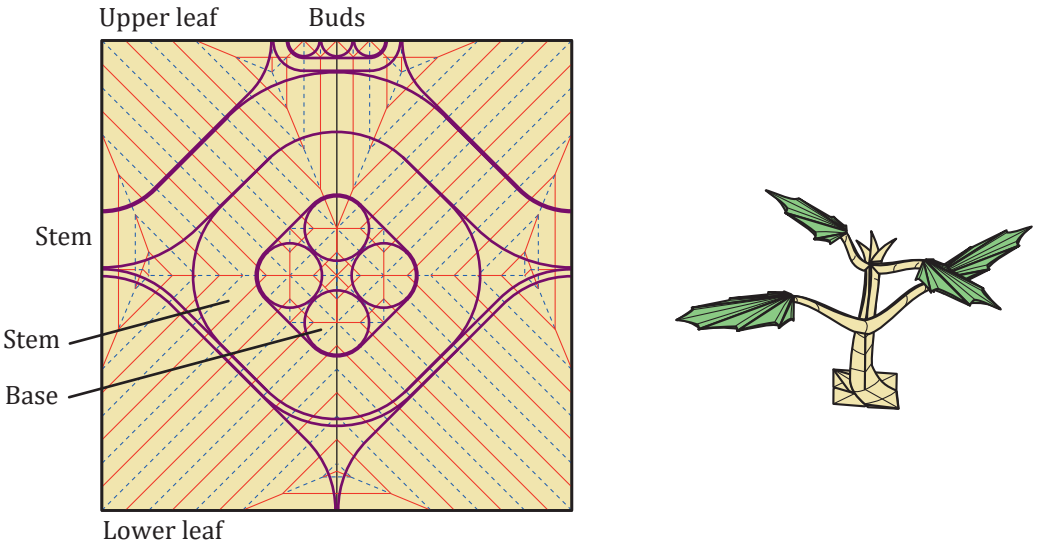
The best way to tackle this sort of conundrum is to extend existing lines rather than make new ones. If we do that here, we obtain an exact square region that we can use for the model to stand on. We even have some spare paper in convenient places to use as catkins (the hanging flowery parts of a Nettle). Filling in the rivers and adding a few extra details gives the crease pattern below – I'll leave making this as an exercise for the budding paperfolder.



Crease pattern and folded model of the Nettle with six leaves.

A second arrangement

Earlier we noted that plants are relatively complex compared to other subjects with a similar number of flaps. So how complex is this six-leafed Nettle? Too complex for my liking. Even with easy-to-find references, symmetry, and a regular pattern to the leaves, it's a tedious model to fold and better left in crease pattern form. For diagramming purposes, we should go for something simpler. So we'll reduce the number of leaves to just four. The final (four-leafed) crease pattern is below.



Crease pattern and folded model for the Nettle with four leaves.

It may seem like I've suddenly plucked this arrangement out of the ether. If you're interested in learning origami design, you might want to know *how* I obtained this pattern. There are three reasons I'm not going to go into great detail about this:

- This reflects the actual experience of the design. I put far more time into the Nettle with six leaves, and after being forced to whittle down the number of leaves gradually, the pattern above was relatively obvious: like a number of traditional bases, we can use the four raw corners for the four long flaps.
- I don't want to give the impression there's anything objectively clever or special about this arrangement. There are lots of equally valid patterns with different pleat numbers and flap lengths: you might like to explore some of the other possibilities.
- It's just as insightful (if not more so) to learn from failures than successes. You might think it's hyperbole to call the six-leafed Nettle a failure, but I had a particular vision in mind and had to adjust my original expectations significantly because of how difficult origami plants are compared to other subjects. That's the real lesson in this chapter.

Let's make this last point quantitative: this Nettle has four large flaps (with colour changes at the end), one medium flap, and some very small details, but has over 80 steps. The Two-headed Goose, which is the most similar model in this book in terms of flap count, has only 40 steps. So we can make a (very) approximate conclusion: expect an origami plant to be about twice as tricky as a model with an equivalent flap layout that has a simpler lump/line configuration.

CUTETHULHU

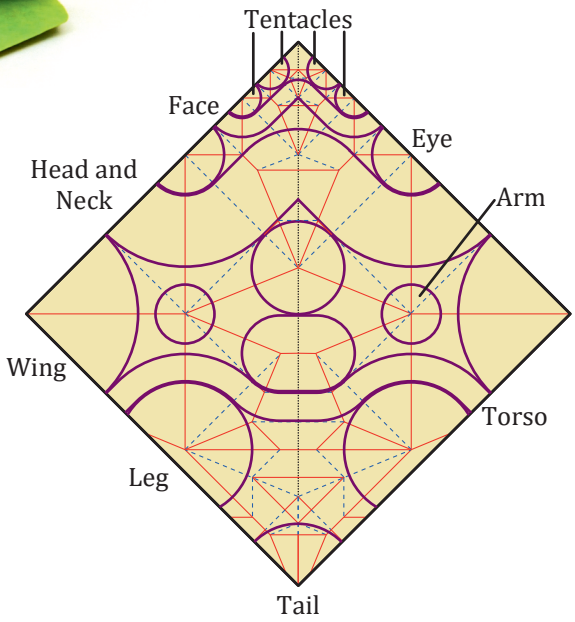
First time: 30cm/12''

Paper preferences:
- Thin
- Shapeable
- Tearproof

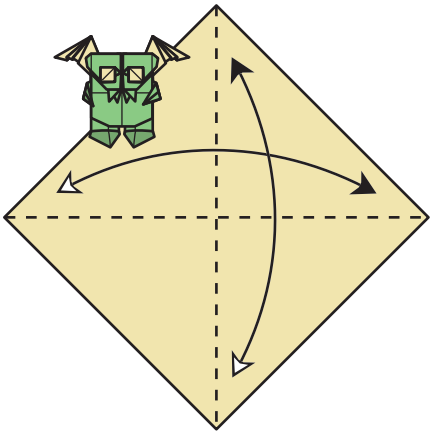
Recommended paper:
- Sandwich paper

Cthulhu is the giant (and thankfully fictional) creature in H. P. Lovecraft's *The Call of Cthulhu*. It has a vaguely humanoid form but possesses the wings of a dragon and, most iconically, an octopus for a head. This being has been popularised in many other horror-based works of fiction.

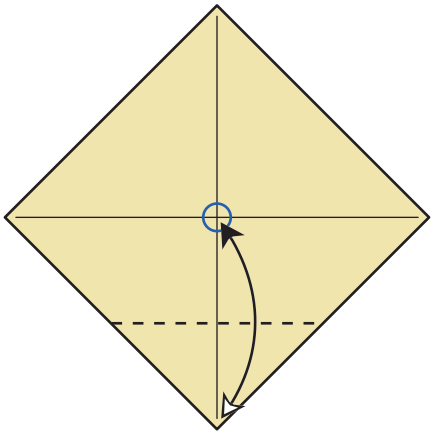
I was inspired to make this design by some street artwork depicting a much less sinister Cthulhu than would be expected of something bearing the description above.



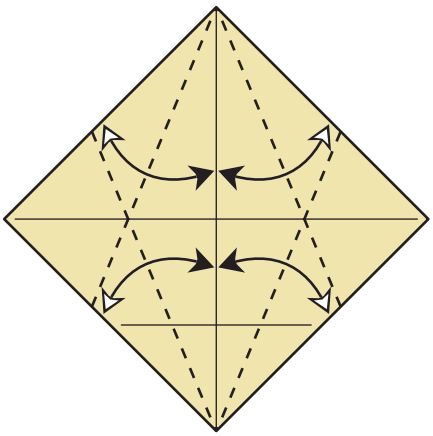
Start eye/wing colour side up.



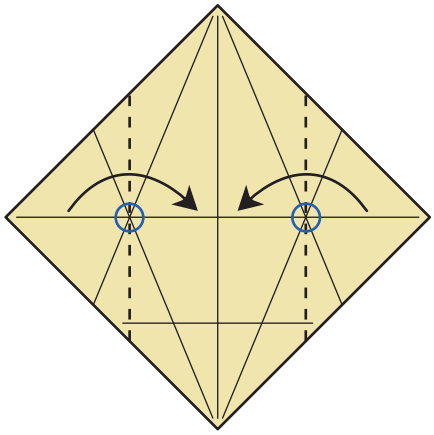
1. Fold and unfold the diagonals.



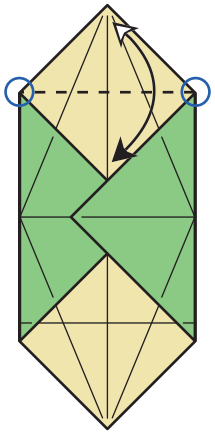
2. Fold the bottom raw corner to the centre and unfold.



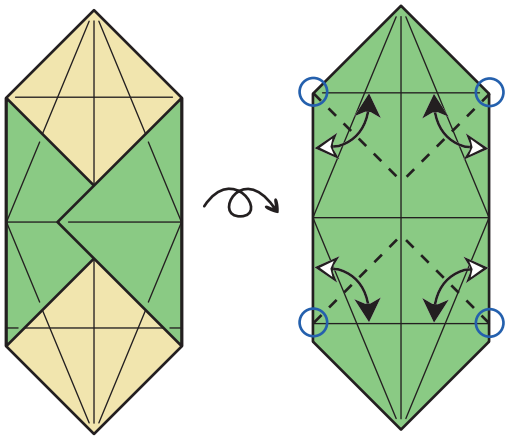
3. Fold the raw edges to the vertical crease and unfold.



4. Fold the raw corners in using the references shown.

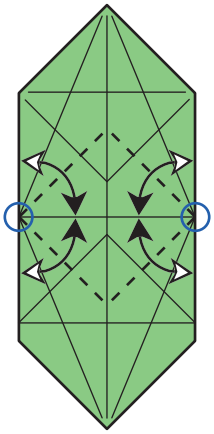


5. Fold the top raw corner down and unfold.

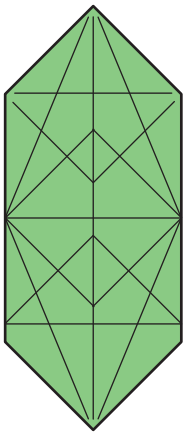


6. Turn the paper over.

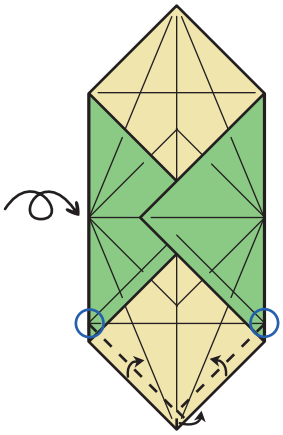
7. Fold and unfold the vertical edges to the horizontal creases.



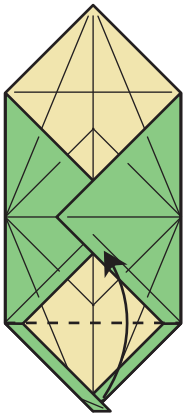
8. Fold and unfold the vertical edges to the horizontal crease.



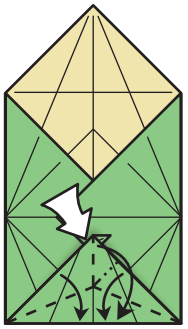
9. Turn the paper over.



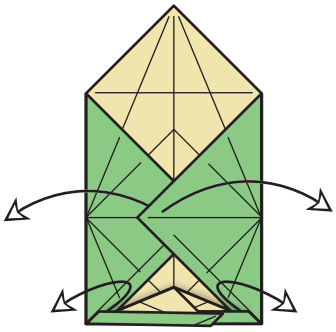
10. Fold a small rabbit ear using fold-lines through the circled points which are parallel to the raw edges.



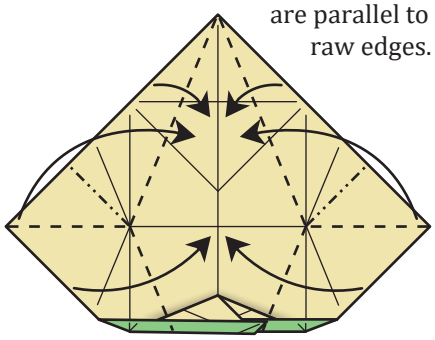
11. Fold up using an existing crease.



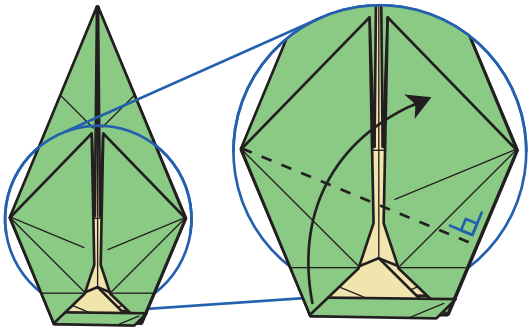
12. Rabbit-ear the corner.



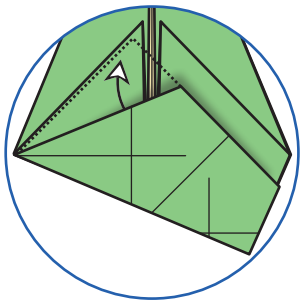
13. Unfold the raw corners.



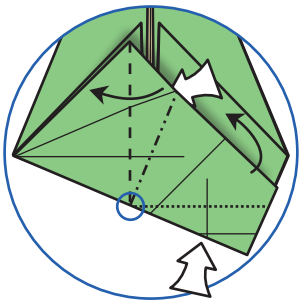
14. Rabbit-ear the corners.



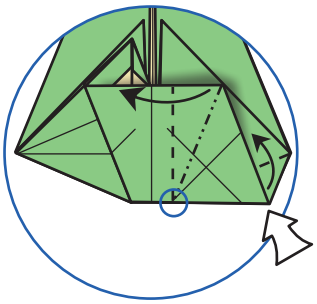
15. Fold the lower section up, using a crease which exists in the near layer on the left.



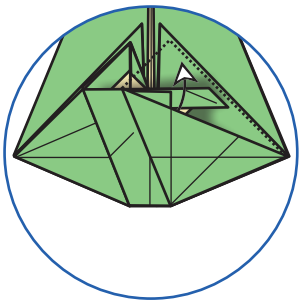
16. Pull out some paper.



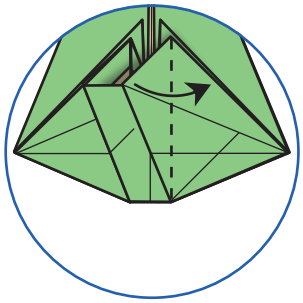
17. Swivel-fold, pivoting about the circled point.



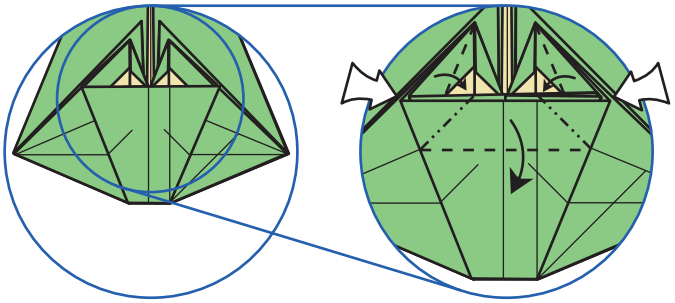
18. Swivel-fold the corner to the left, pivoting about the circled point.



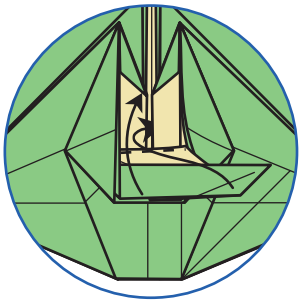
19. Pull out some paper.



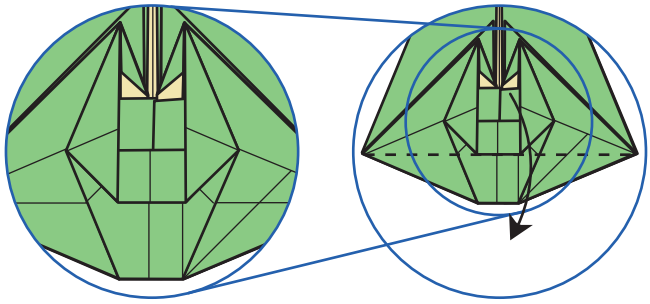
20. Fold the flap to the right.



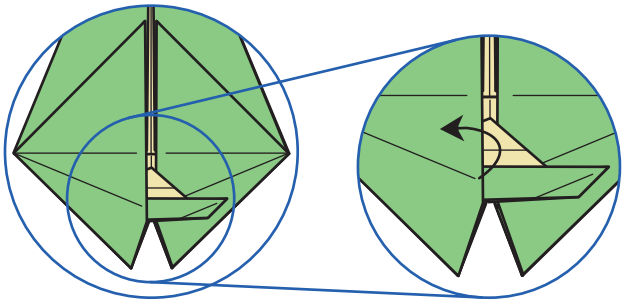
21. Petal-fold the folded edge down, while bringing the raw corner to the front. The paper won't lie flat until after step 22.



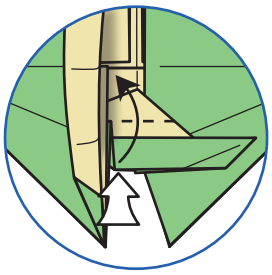
22. Fold the inner edge up, and tuck the raw corner behind the right-hand edge, as shown.



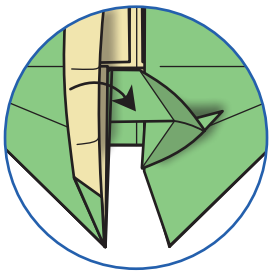
23. Fold the connected layers down.



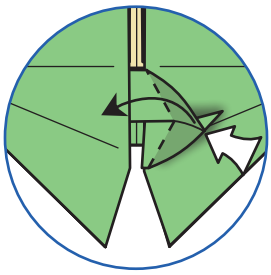
24. Lift the raw edge. The paper won't lie flat until after step 27.



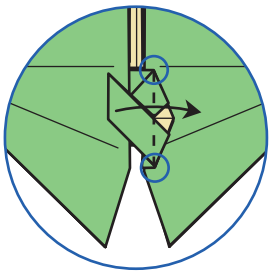
25. Reverse-fold the left portion of the edge upwards.



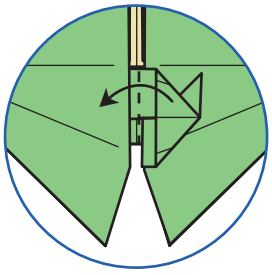
26. Fold the raw edge back down.



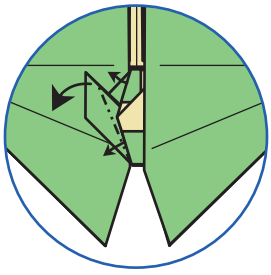
27. Squash-fold to flatten the paper.



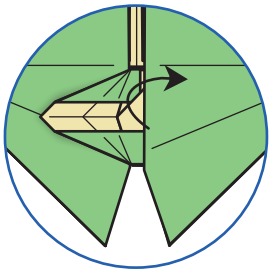
28. Fold the small corner to the right as far as it will go.



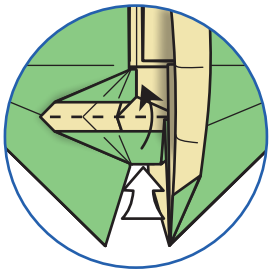
29. Fold the whole flap to the left as far as it will go.



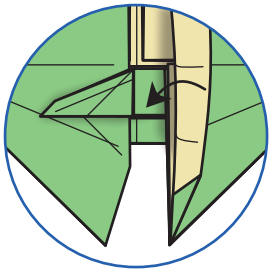
30. Spread and flatten the paper to the left.



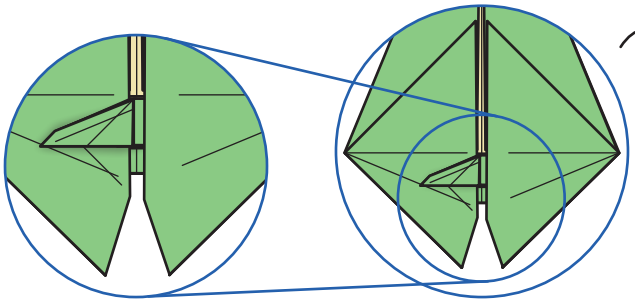
31. Lift the raw edge. The paper won't lie flat until after step 33.



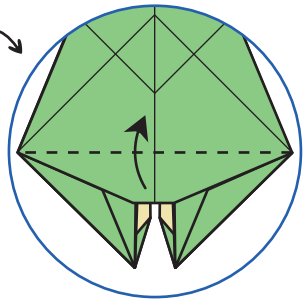
32. Reverse-fold the edge upwards.



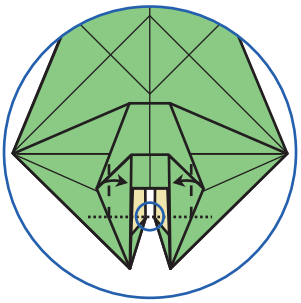
33. Fold the raw edge back down.



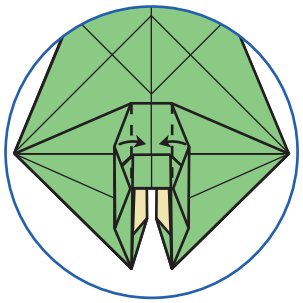
34. Turn the paper over.



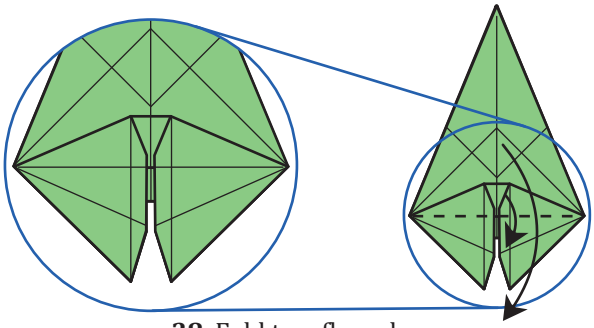
35. Fold the flap up.



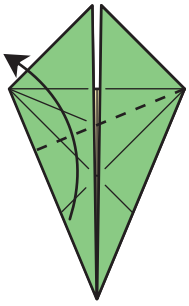
36. Fold the corners in. The bottoms of the fold-lines are level with the circled points.



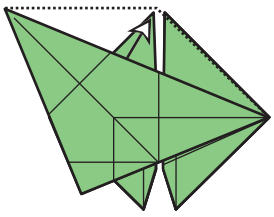
37. Fold the flaps in.



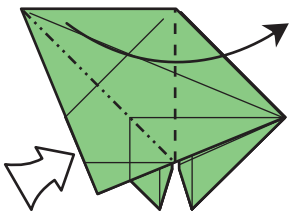
38. Fold two flaps down.



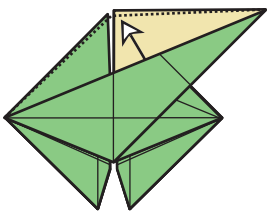
39. Fold the point up and to the left, extending an existing crease.



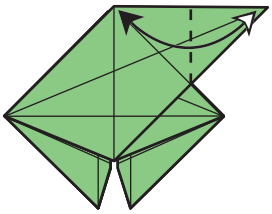
40. Pull out some paper.



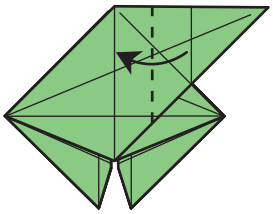
41. Swivel-fold the corner to the right.



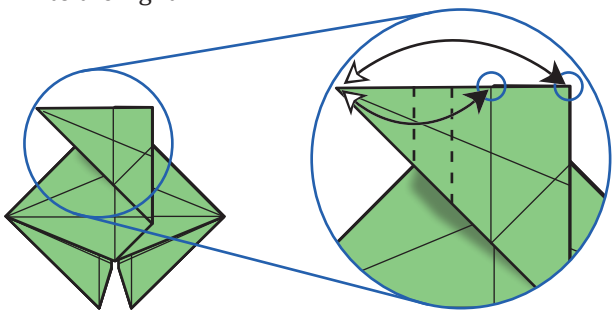
42. Pull out some paper.



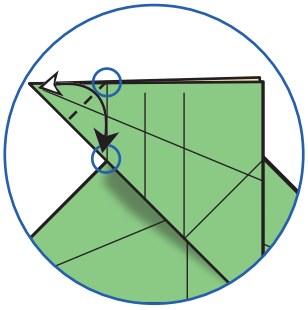
43. Fold the raw corner to the centre and unfold.



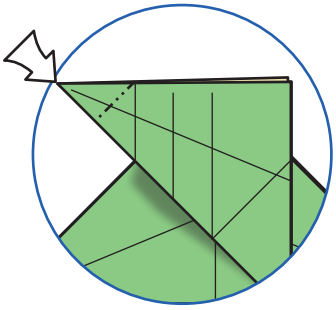
44. Fold the crease you just made onto the central vertical line.



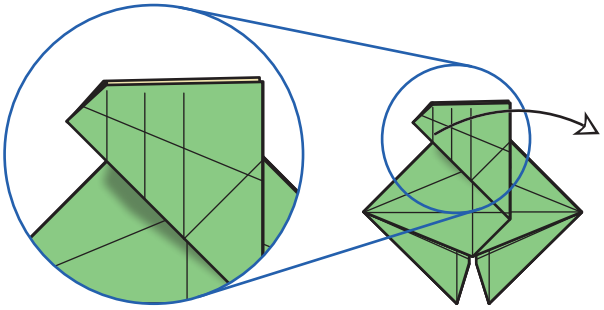
45. Fold and unfold the raw corner to the circled points.



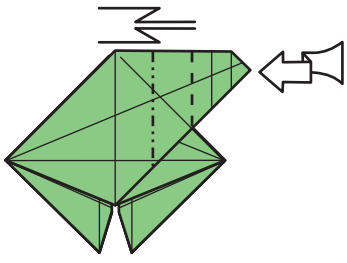
46. Fold the raw corner down and unfold.



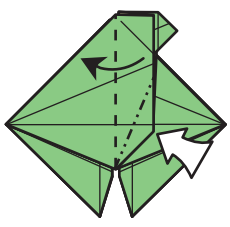
47. Reverse-fold using the creases you just made.



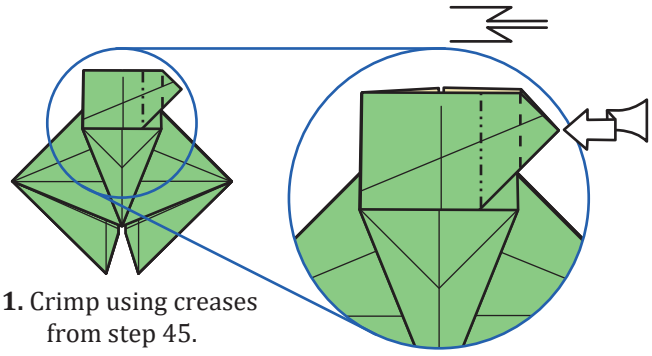
48. Unfold step 44.



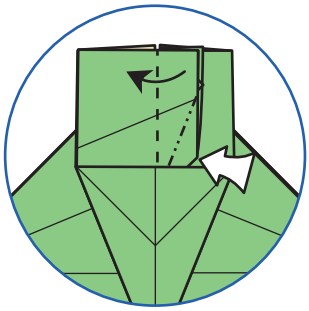
49. Crimp using creases from steps 43 and 44.



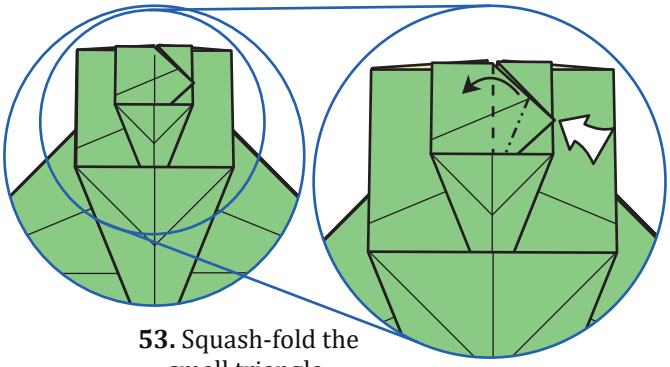
50. Spread-sink the corner.



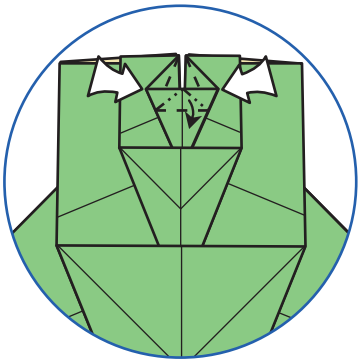
51. Crimp using creases from step 45.



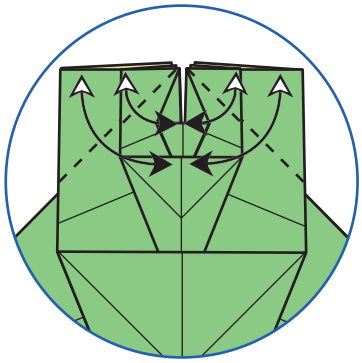
52. Spread-sink the corner.



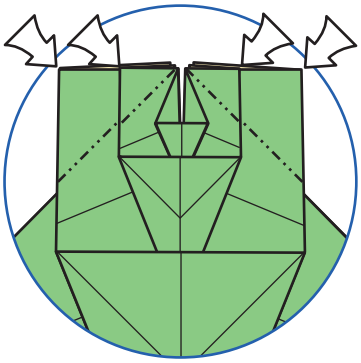
53. Squash-fold the small triangle.



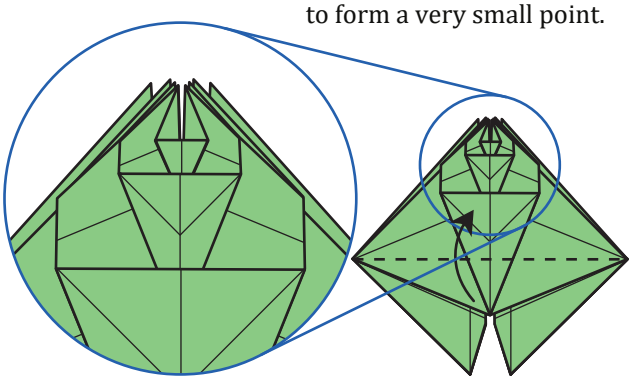
54. Petal-fold the edge down to form a very small point.



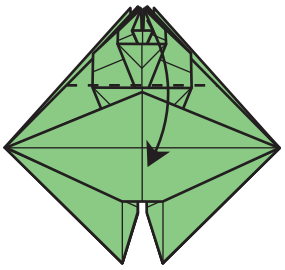
55. Fold and unfold four angle bisectors.



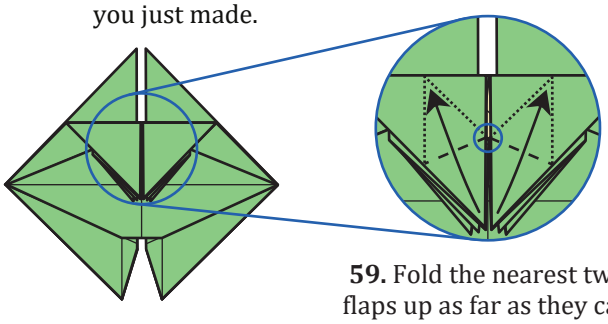
56. Reverse-fold four corners using the creases you just made.



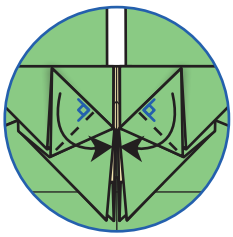
57. Fold one flap upwards.



58. Fold the connected flaps down along the folded edge.

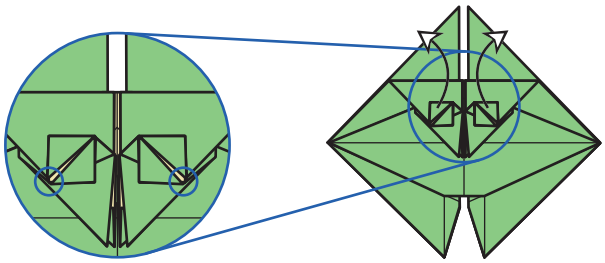


59. Fold the nearest two flaps up as far as they can go so that the outer edges become vertical.

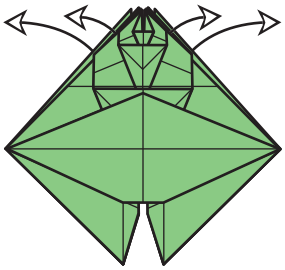


60. Fold the corners down so the vertical edges become horizontal.

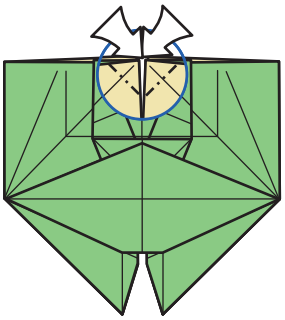
61. Squash-fold the points.



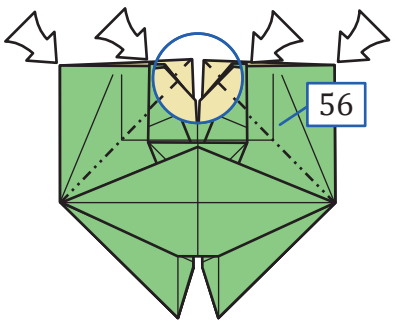
62. Note the circled corners. Unfold steps 58 to 61.



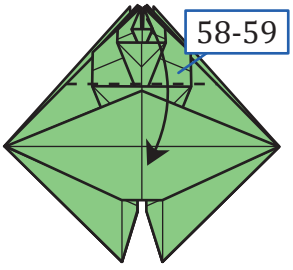
63. Undo the two reverse folds on each side which surround the corners circled in step 62.



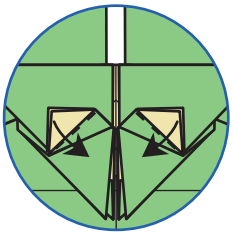
64. Reverse-fold the circled corners from step 62 using existing creases (from the squash-fold in step 61).



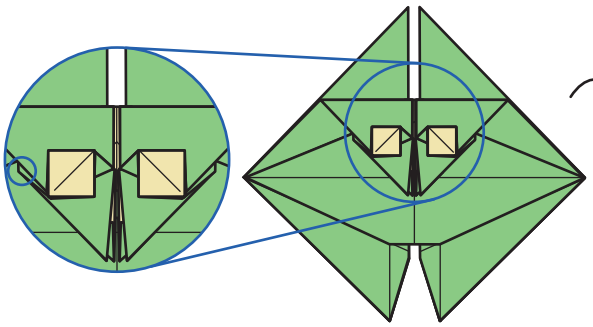
65. Repeat step 56: refold the reverse folds undone in step 63.



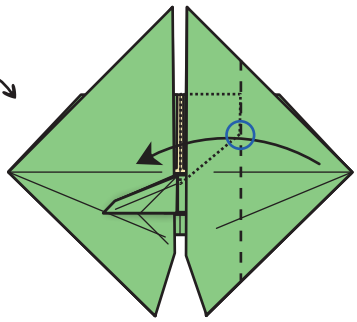
66. Repeat steps 58 and 59.



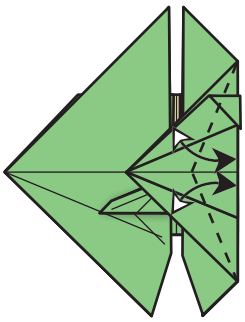
67. Fold one white triangle down on each side.



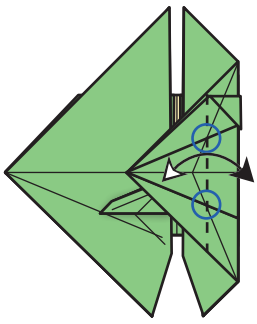
68. Note the circled point – this will be used in the next step. Turn the paper over.



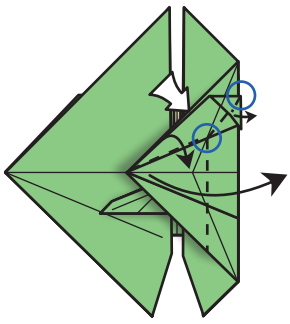
69. Fold the right corner to the left along a hidden vertical line.



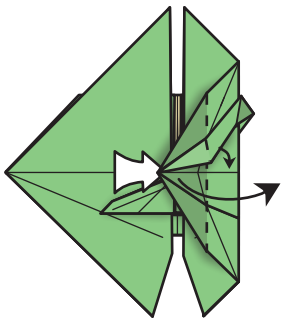
70. Fold and unfold two angle bisectors.



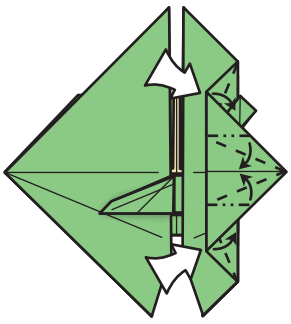
71. Fold and unfold a vertical line which goes through the circled points.



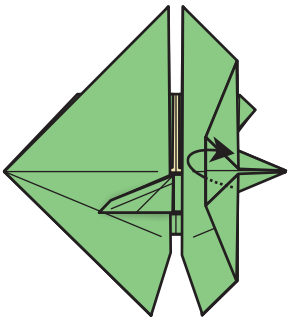
72. Use a new valley fold which connects the circled points to swivel-fold the corner back to the right. The paper won't lie flat until after step 73.



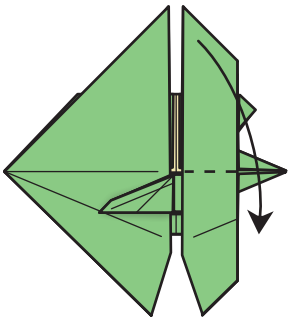
73. Flatten the paper.



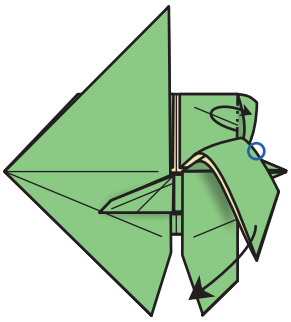
74. Swivel-fold twice to narrow the corner on the right.



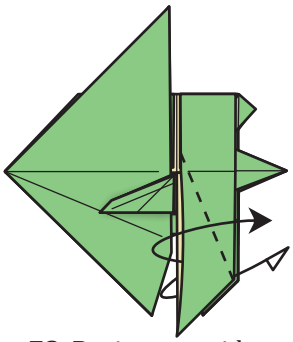
75. Carefully wrap the hidden valley fold around to the front so that it becomes a mountain fold. You can do this by folding the layer to the right and closed-sinking if you prefer.



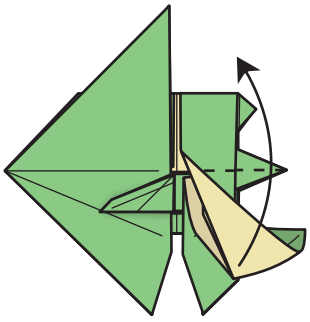
76. Gently bring the raw corner down towards you. The paper won't lie flat until after step 77.



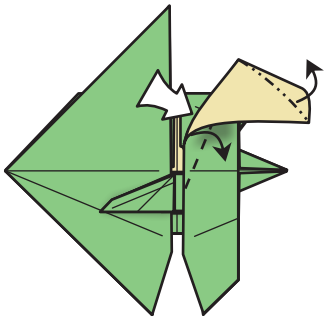
77. Carefully flatten the paper, extending the circled mountain-folded edge all the way to the top, bringing it to the front. You'll need to unfold the paper somewhat to achieve this.



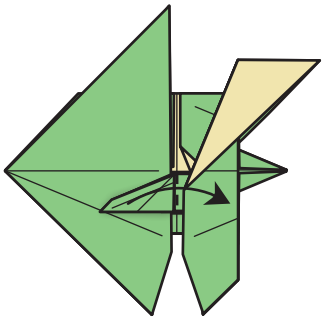
78. Begin to outside-reverse-fold the raw edge around to the right, using a fold-line which is along a hidden folded edge. The paper won't lie flat until after step 80 (when this outside reverse fold is completed).



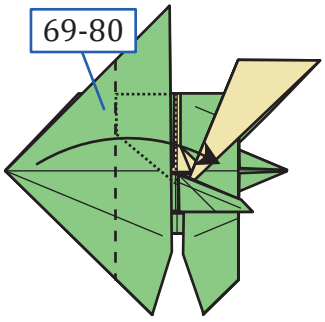
79. Fold the flap up.



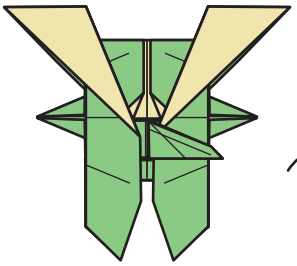
80. Flatten the paper using a fold-line which aligns with the folded edges behind it.



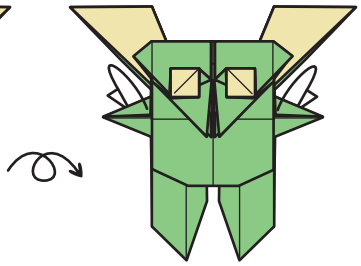
81. Fold the tail to the right.



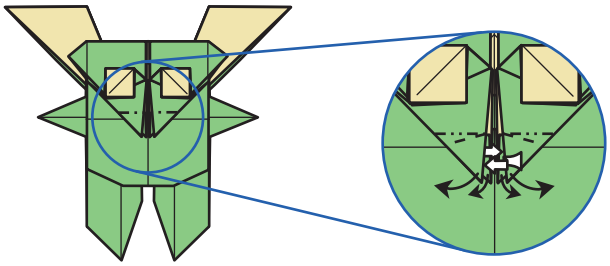
82. Repeat steps 69 to 80, flipping left and right.



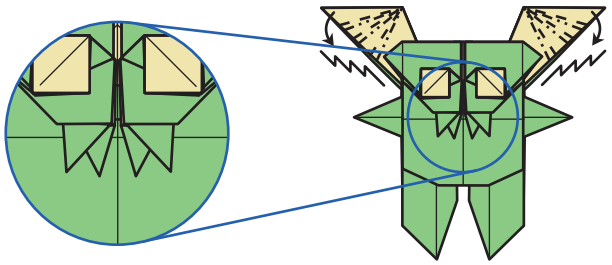
83. Turn the paper over.



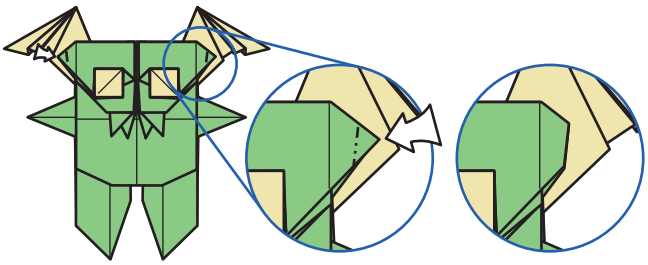
84. Wrap the upper layer of the arms behind.



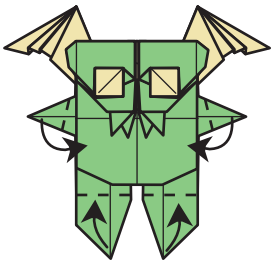
85. Spread the small tentacles evenly with crimps.

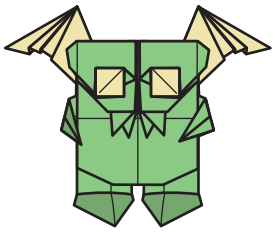


86. Pleat the wings.



87. Reverse-fold the small corners at each side of the head a little.

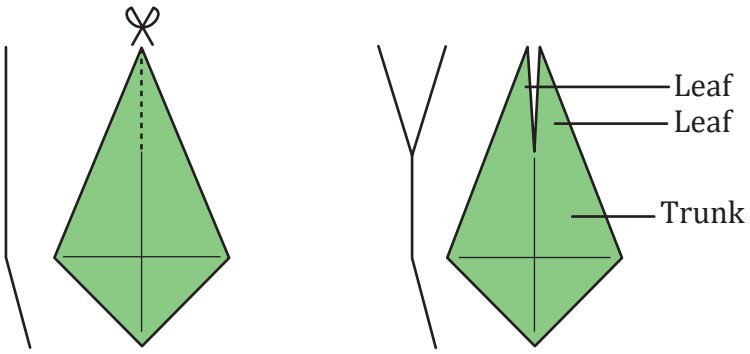




88. Fold the arms in and fold the feet up so the model stands.

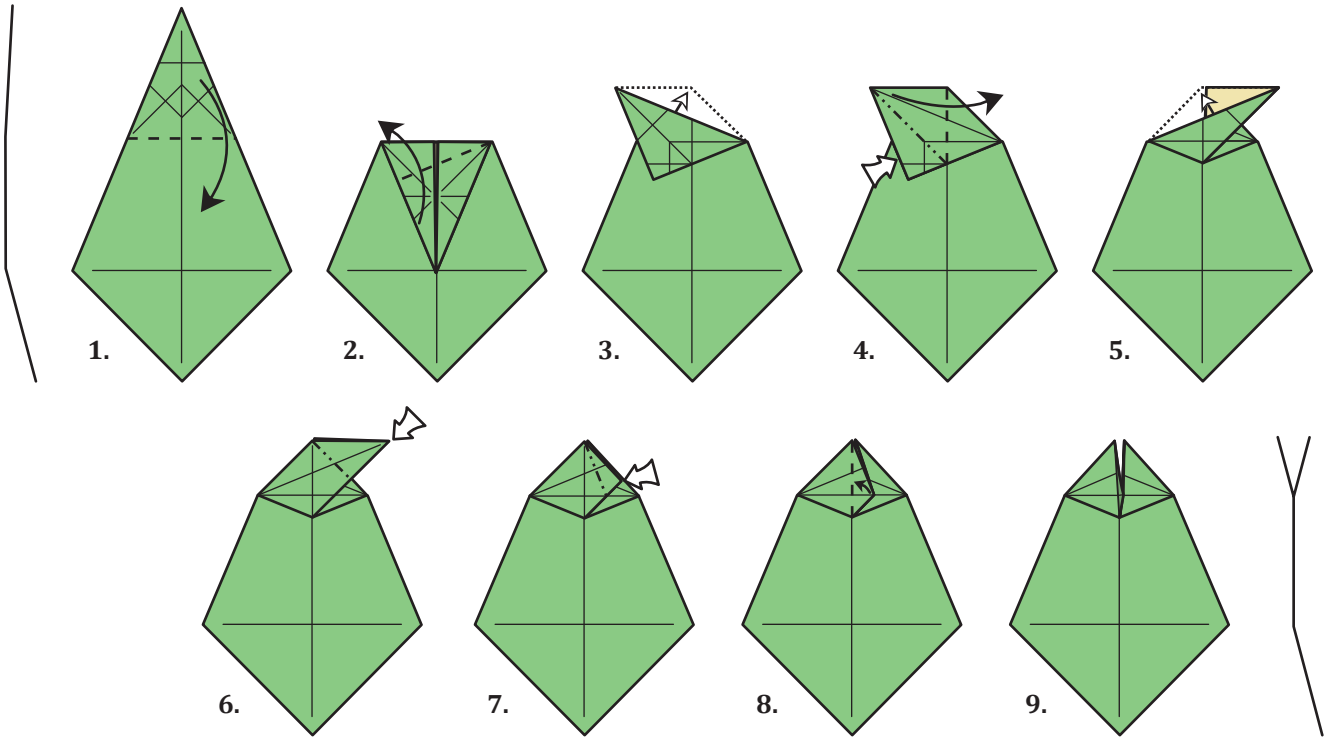
Point Splitting

One of the standard techniques in the origami designer's repertoire is being able to turn a single flap into multiple flaps. This is called **point splitting**. Historically, this was achieved by cutting a flap down the middle, which creates two new flaps with the same length as the original flap. In the context of point splitting, let's call each new flap a **leaf** and the uncut section the **trunk**.



Cutting to create more flaps, with the trees of the paper before and after cutting. Can we mimic this without resorting to scissors?

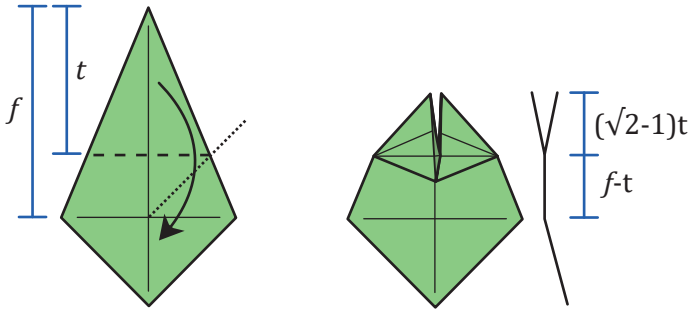
An origami purist winces at this approach, and will only be satisfied with a method where the paper remains intact. Perhaps the most popular method of point splitting is shown below, which I'll call the **2-split**. The first part of this sequence is used in steps 39 to 43 of Cutethulhu. A similar sequence occurs in steps 37 to 49 of the Gnome on page 18.



A folding sequence for the 2-split, which converts one long flap at a raw corner into two leaves (precreases have been made in advance for brevity). Note that the leaves are now both edge flaps.

Although the split occurs halfway down the original flap in both methods, the leaves are much shorter when folding than when cutting – the ratio turns out to be $\sqrt{2}-1 \approx 0.41$, i.e. the folded leaves are only about 40% as long as the cut leaves. To get longer leaves, more paper has to be used in the point split. This can be done either by making the first fold lower, which reduces the length of the trunk, or by increasing the size of the whole initial flap.

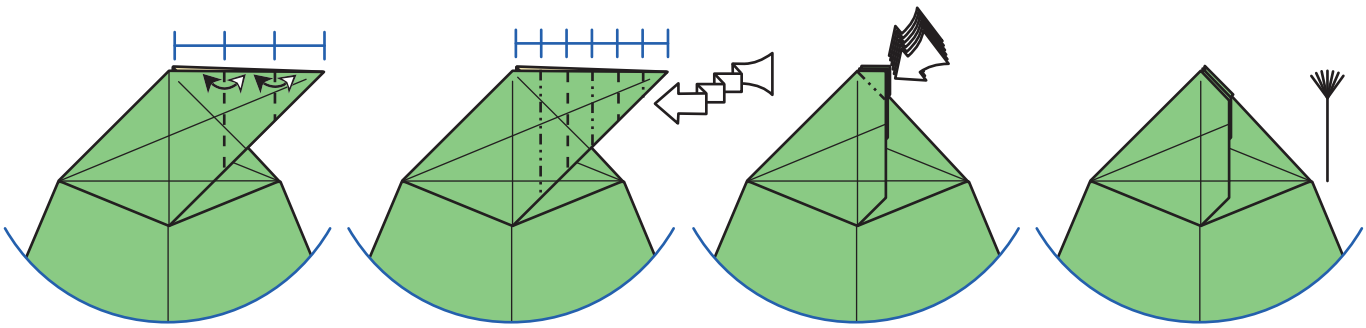
Put numerically, if we call the length of the starting flap *f*, and say that the split occurs at a length *t* from the tip, then the trunk has length *f*-*t* and the leaves have length $(\sqrt{2}-1)t$. This can be useful when designing with particular requirements in mind. For example, to split a flap so that the leaves and trunk have the same lengths, we need $f-t = (\sqrt{2}-1)t$. Solving this leads to $t/f = \sqrt{2}/2$, which allows us to locate the initial fold (after measuring or performing a bit more mathematics to find an exact sequence).



A small bit of algebra can help find an initial fold to obtain leaves and trunk with desired lengths.

Can we get more points?

We'd rapidly exhaust the usefulness of point splitting if we could only ever obtain two points. We can adjust the 2-split sequence to get a general method for obtaining *n* equal leaves, and we'll call this an **n-split**. One method for this is shown below.



1. Start with the first 5 steps of the 2-split. Then divide the top edge into $n/2$ (rounded down) sections.

2. Reverse-fold in and out.

3. Reverse-fold several times. If n is even, reverse-fold the middle corner too.

Folding an n-split. These diagrams use $n = 7$.

When *n* is even, the above sequence can be made slightly more efficient. I'll leave you to experiment with this.

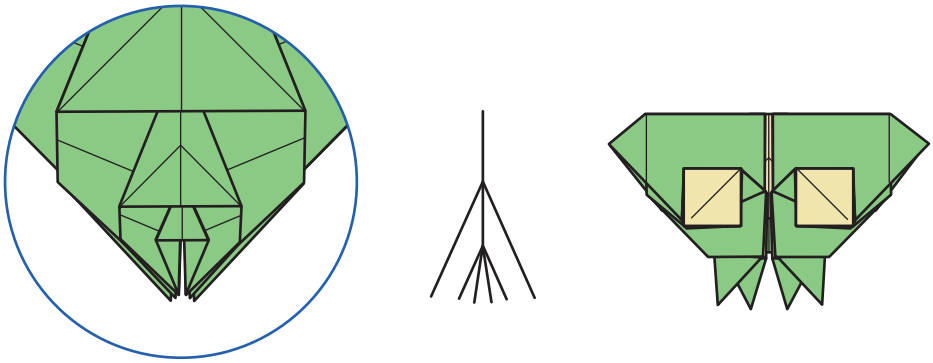
You'll notice that the length of each leaf decreases as *n* increases, which in turn adds length to the trunk. In practical terms, this means that making a large number of points is physically challenging and ineffective, unless you only want very small points.

Leaves of different lengths

The trees for the point splits seen so far are relatively simple, but there is no reason to have all leaves the same length. The easiest way to do this is by varying the distance between the vertical lines in the n-split.

Recall that longer leaves reduce the length of the trunk. Therefore, there will inevitably be new rivers introduced between leaves of different lengths, because these leaves will branch out from different positions on the tree.

Steps 39 to 56 of Cutethulhu show how to make the flaps for the eyes longer than the tentacles. This works particularly well, because the new river in the tree is formed between the eyes and the tentacles, which separates these features in the final model.

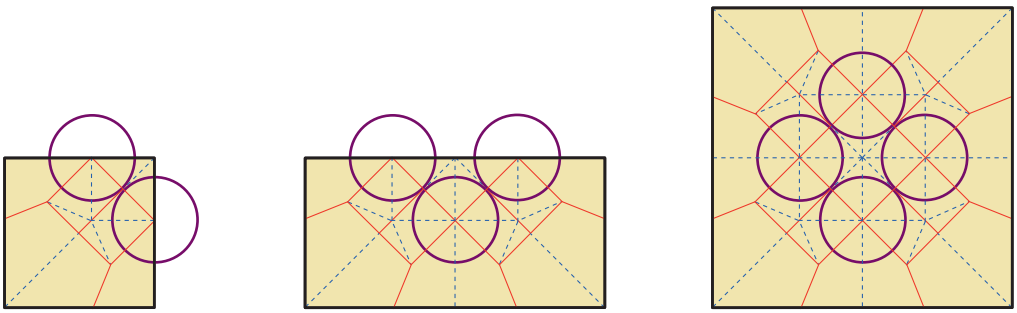


Base (step 57), tree, and finished head of Cutethulhu.

What about flaps which aren't raw corners?

Thus far, we've only looked at point splitting raw corners. (In fact, we've only seen one type of raw corner flap – the one that arises most frequently in 22.5° geometry. As an aside, you may like to consider how we would split other types of raw corner flap.) Point-splitting at raw corners is by far the most prevalent form, at least in my models. This is because one of the main draws of point splitting from a design perspective is that we don't need to make as many flaps when planning the base of a model. With fewer flaps, there is a much greater likelihood that we can make a large flap out of a raw corner and so we often don't need to use other types of splits at all.

For when we do need to split edge or middle flaps though, we can make equivalents of the 2-split simply by duplicating the 2-split crease pattern, as shown below. However, these are much more difficult to fold than raw corners because there are more layers of paper in edge and middle flaps (see steps 25 to 40 of the Minotaur on pages 75 and 76). It's a good (and difficult) exercise for you to have a go at using the same technique to fold duplicated n-splits on an edge or middle flap too.



Left: Crease pattern for the raw corner 2-split. Centre: Two copies of the 2-split creates a crease pattern for splitting a raw edge. Right: Four copies of the 2-split creates a crease pattern for splitting a middle flap. (Note that to make the repetition of the 2-split clear, I've repeated the creases exactly, but this means the centre and right crease patterns here are not flatfoldable – you will need to adjust the creases slightly if you want to make these.)

Why use point splitting – isn't grafting better?

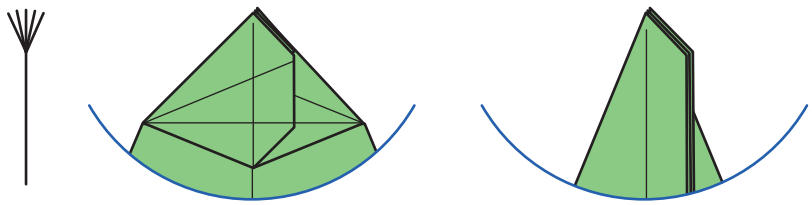
As a very brief reminder, grafting involves folding an existing model but from only part of a sheet of paper so that there is leftover paper, for example at a raw corner. This leftover paper can be used to add extra details to the original design. (If you aren't familiar with this concept, you can see an example on page 89, or find more discussion and examples of grafting in *Folding Fantasy: Volume 1*.) You may notice that grafting and point splitting have some similarities: both are modern design techniques which can be used to create more points. On the surface, grafting seems superior: you can graft anywhere (not just on long flaps), and the new leaf flaps can be arbitrarily long by inserting the desired amount of paper.

However, there are some key advantages of point splitting over grafting:

• **Ease of folding**: It's easy for designers to undervalue or even overlook this point (I'd know!). Point splits are particularly common in designs using 22.5° geometry, which means they can be readily applied to existing traditional bases. It's much more comfortable for a less-experienced folder to begin a model by, say, folding a traditional Bird Base then point split one of the flaps, than to begin with some unfamiliar grafting, even if the grafted paper will subsequently be folded Bird Base afterwards. It's also trickier (and messier) to fold multiple flaps with different lengths when grafting, whereas we've already seen that this is fairly straightforward with point splitting.

• **Convenient configurations**: Point splitting decreases the number of options to search through when approaching a design by circle packing, because we can group different subsets of our flaps together to make simpler trees (see page 47). Even though the subflaps will still be in about the same location no matter the grouping, it becomes much easier to spot a suitable arrangement of circles, like the Fish Base in Cutethulhu. Although grafting after finding a base also simplifies the initial tree, the extra paper along the whole graft needs accounting for and needs more work to be used efficiently.

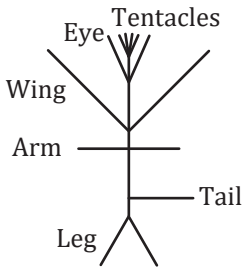
• **Wider flaps**: Point splitting naturally leaves you with relatively wide flaps compared to grafting. Whether this is a good thing depends on the subject, of course.



Left: A tree. Centre: Point-splitting a 45° flap to create the tree. Right: Grafting down the middle of a 45° flap to create the tree. Point splitting gives a wider flap.

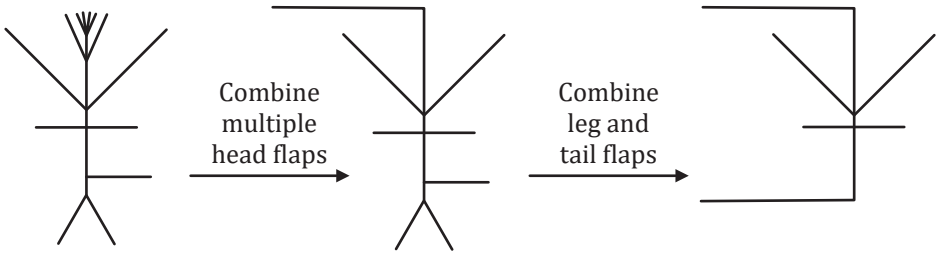
• **Flap independence**: One of the great boons of point splitting is that it allows the designer to create a model in stages rather than all at once, by introducing an extra stage in the standard design process. This is most easily demonstrated by example, so let's continue to analyse Cutethulhu. We've already seen how we can use point splitting for the head, but let's backtrack and consider the whole design journey for this model.

1. Assess the subject and make a tree.



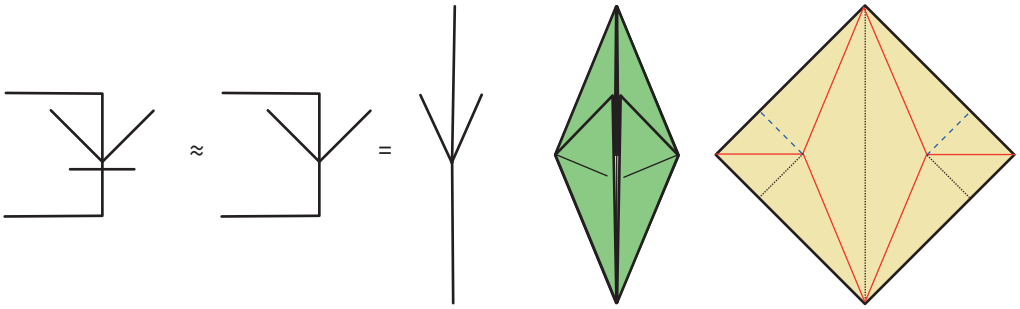
A rough tree for Cutethulhu. (The flaps on the head are upside-down because this means that the small flaps can all be made from the raw edge. This means we'll need to fold the head down at some point during the folding process, which is not a problem.)

2. Simplify the tree, by combining some of the smaller flaps into one big flap.



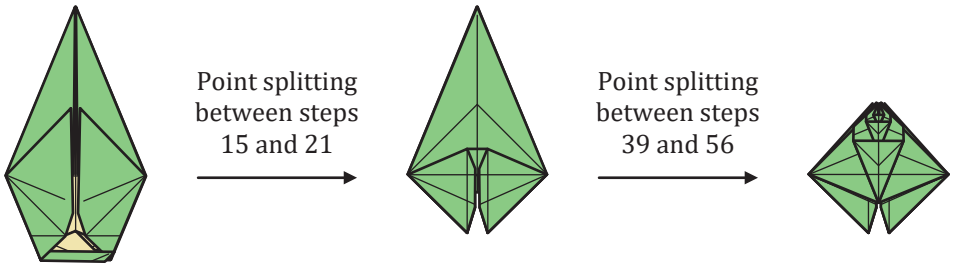
Combining the head flaps prompts us to consider combining the legs and tail into one flap too. This results in the top and bottom halves of the tree being symmetric, which will make creating a base much easier.

3. Create or identify a base which matches the simplified tree.

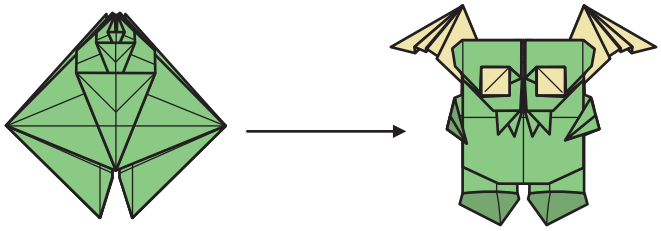


If we ignore the smallest flaps, the traditional Fish Base matches the tree. We'll worry about those small flaps later and press on for now.

4. Point-split the large flaps to recreate the smaller flaps that were removed in stage 2.



5. Finish folding the model.



The obtuse angles in the Fish Base can be manipulated into small arms, and then we have all the flaps we need to fold the final model.

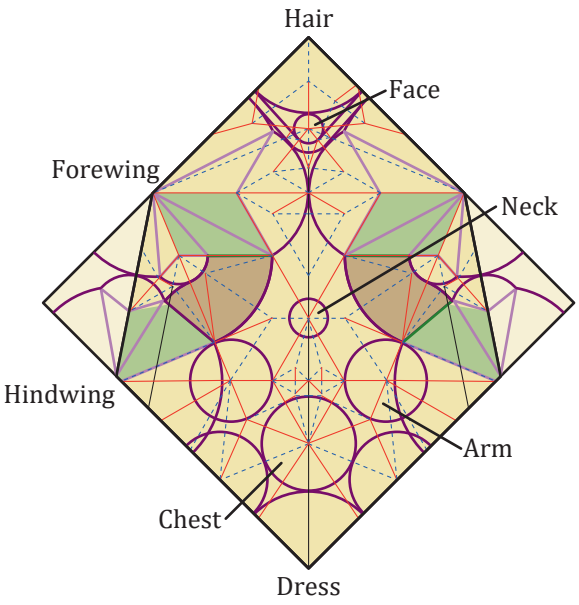
If instead, we'd decided to use a vertical graft to add the head and leg flaps, there would be no equivalent to the independent point splits in stage 4. This is because a graft propagates across the whole square, so we would have needed to consider the paper required for the top and bottom flaps simultaneously, if a graft which is suitable for both ends even exists. But by point-splitting, we can fold the head separately from the legs. In fact, we can even adjust the height of the head at this stage: the horizontal valley fold in step 38 was only used for convenience, but a taller model can be made by using a fold-line which is closer to the top of the paper. I'd recommend giving this a go!

Psyche

First time: 40cm/16"

Paper preferences:
- Duo
- Shapeable
- Tearproof

Recommended papers:
- Sandwich paper
- Foil-backed paper

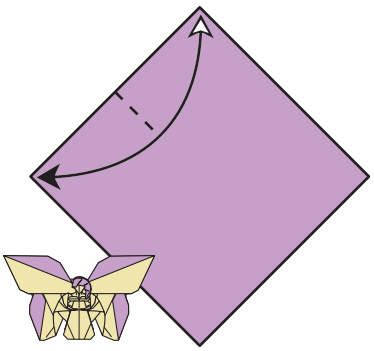


In Greek mythology, Psyche is the beautiful goddess of the soul and is often depicted with butterfly wings.

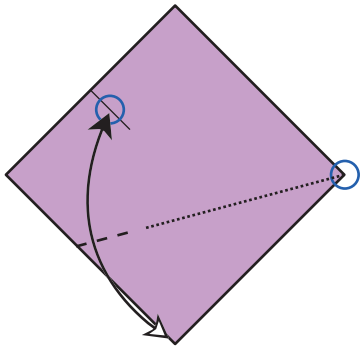
You'll have most success with this model if you use foil, because this helps to mould the details, like the arms, neck, and hair.

For the curious, the unusual crease pattern on the left is explained on page 60.

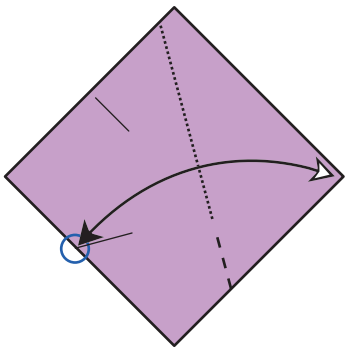
Start hair colour side up.



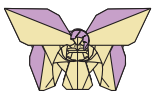
1. Make a small mark halfway along the top left raw edge.

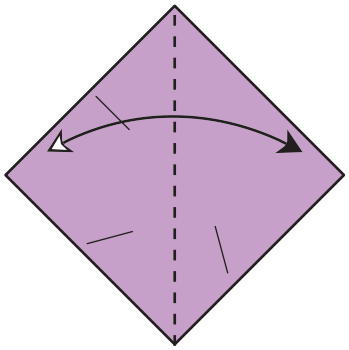


2. Fold the bottom raw corner to the crease, using a fold-line which goes through the right raw corner. Mark the paper firmly only on the left, then unfold.

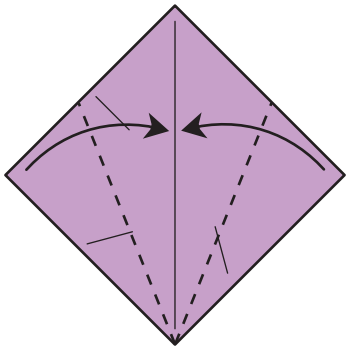


3. Fold the right raw corner to the circled point. Mark the paper firmly only at the bottom, then unfold.

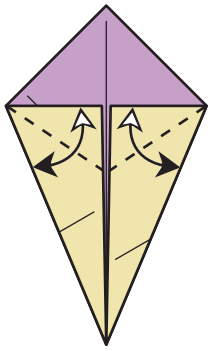




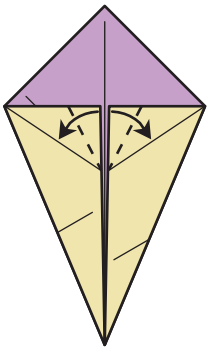
4. Fold the vertical diagonal and unfold.



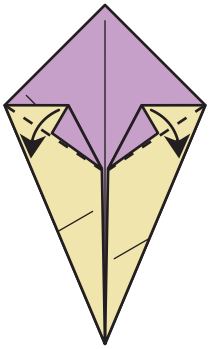
5. Fold the raw edges to the centre.



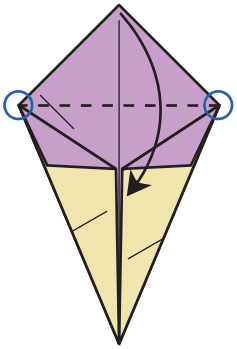
6. Fold the horizontal raw edges to the folded edges and unfold.



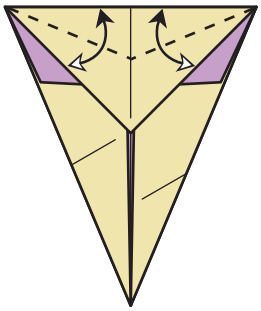
7. Fold two angle bisectors.



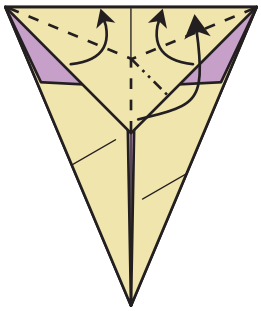
8. Fold along the creases from step 6 again.



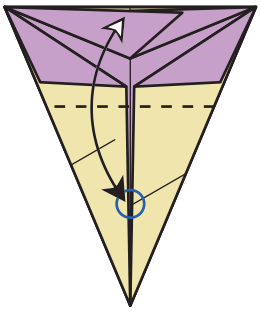
9. Fold the raw corner down.



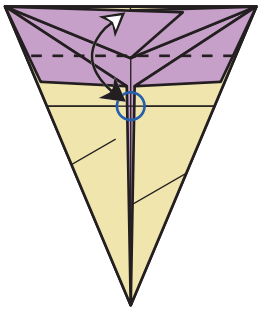
10. Fold and unfold two angle bisectors.



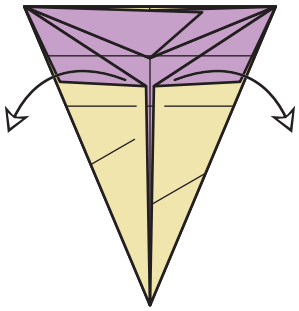
11. Rabbit-ear the raw corner to the right.



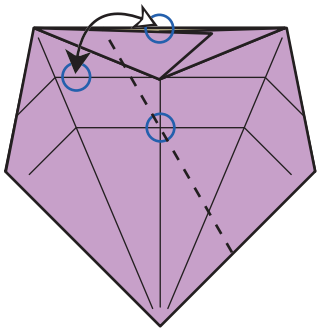
12. Fold the centre of the top edge down to the circled point, then unfold.



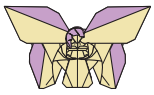
13. Fold the top edge to the crease you just made, then unfold. The fold-line just passes through the near layers.

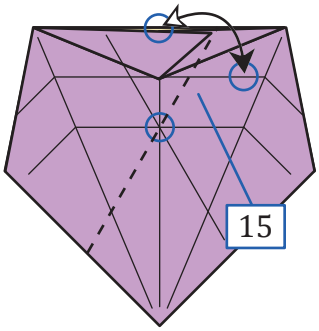


14. Fold the large flaps to the sides (i.e. unfold step 5 but nothing else). Some creases will no longer be shown.

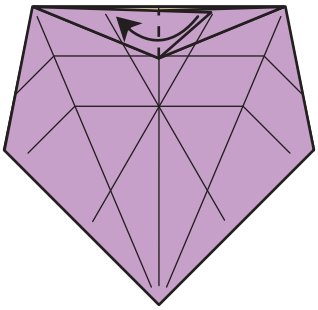


15. Fold the centre of the top edge to the indicated horizontal crease using a fold-line which goes through the circled point in the centre of the paper, then unfold.

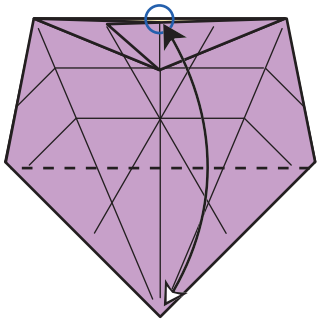




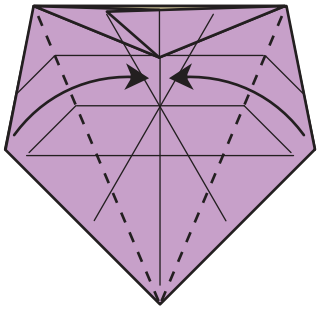
16. Repeat step 15, flipping left and right.



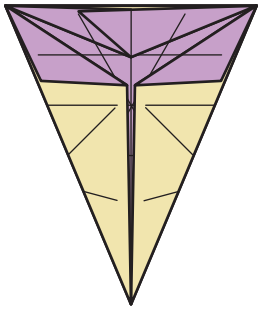
17. Fold the flap to the left.



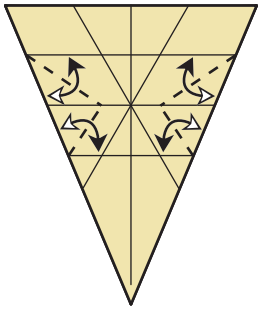
18. Fold and unfold.



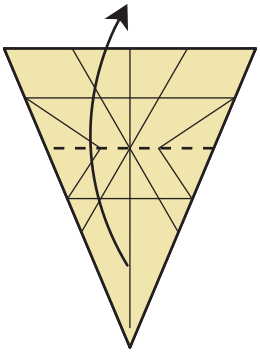
19. Fold the sides in again.



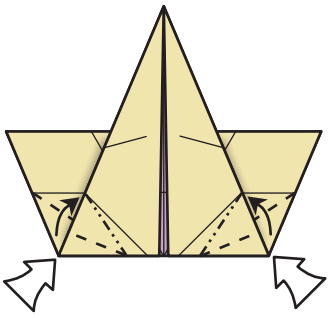
20. Turn the paper over.



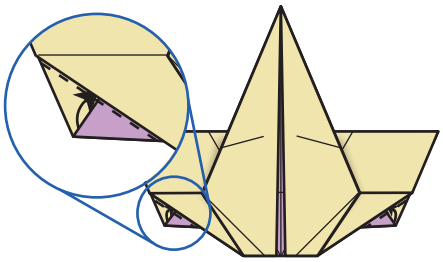
21. Fold and unfold four angle bisectors.



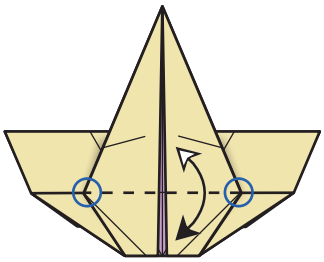
22. Fold the corner upwards.



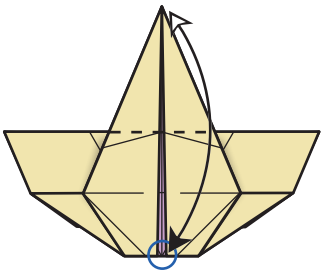
23. Reverse-fold using creases made in step 21.



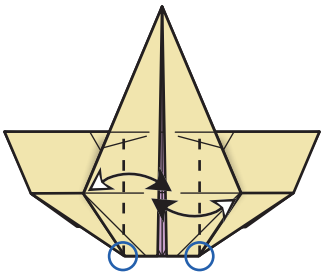
24. Tuck the small coloured corners underneath.



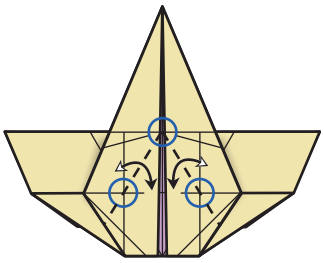
25. Fold the corner down, then unfold.



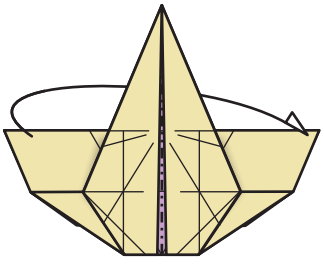
26. Fold and unfold.



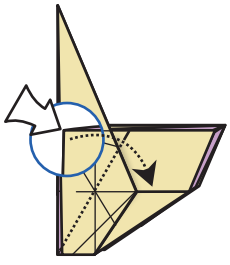
27. Fold and unfold, as shown.



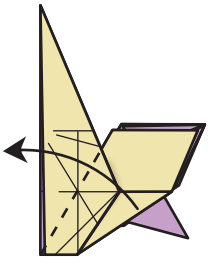
28. Make fold-lines which connect the circled points, then unfold.



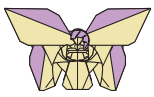
29. Mountain-fold the left half behind the right half.

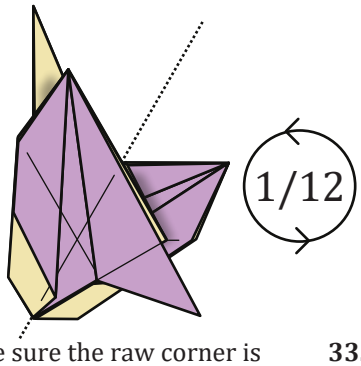


30. Reverse-fold the inner corner using existing creases.

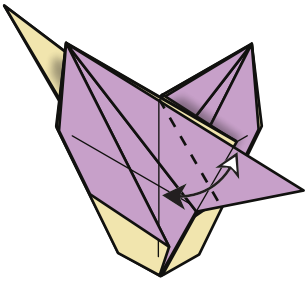


31. Fold one flap to the left.

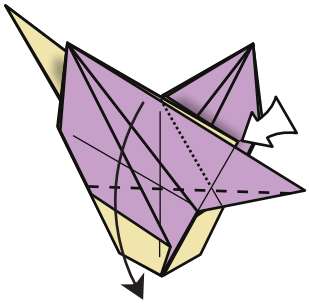




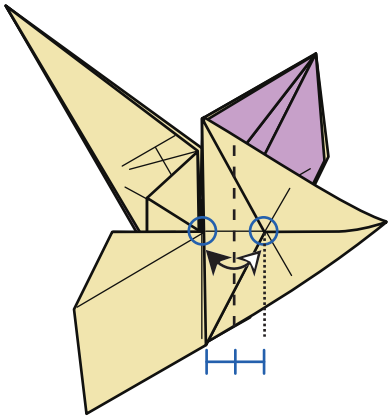
32. Make sure the raw corner is visible, as shown here. Rotate the paper anticlockwise so the dotted line becomes vertical.



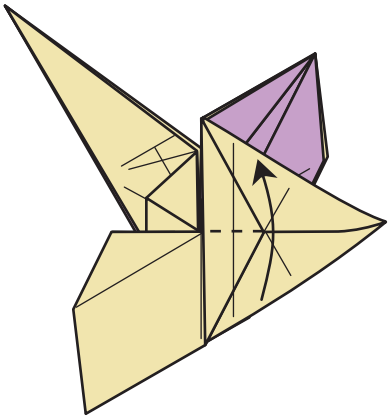
33. Fold an angle bisector and unfold.



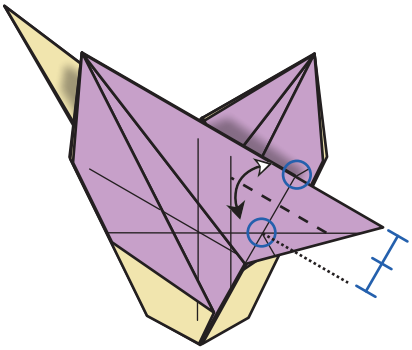
34. Fold the flap down, squash-folding the inner edge. The raw corner won't quite lie flat until after step 36.



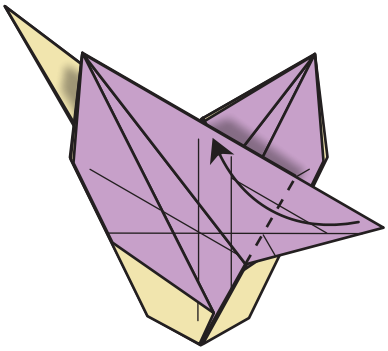
35. Fold halfway between the circled points, then unfold.



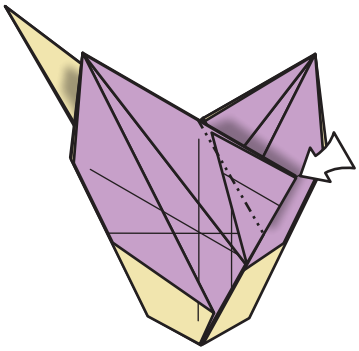
36. Fold the flap back up.



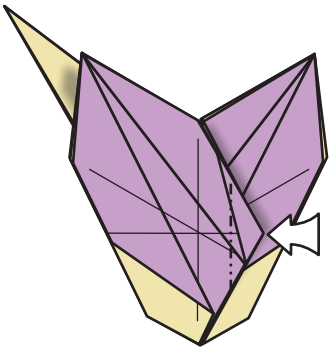
37. Carefully fold both raw edges down using a fold-line which is halfway between the circled points, then unfold. The second layer is rather restricted; fold as much as you can, but don't worry if you only make a partial fold.



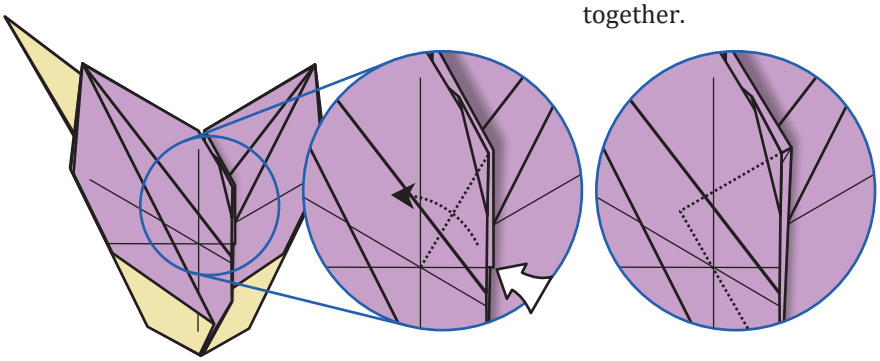
38. Fold the raw corner to the left.



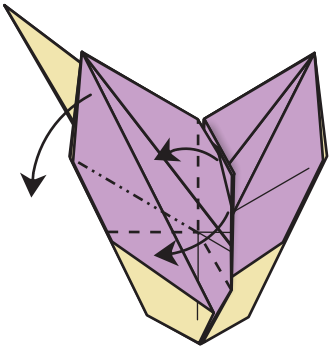
39. Treat the raw corner as though it is attached to the layer behind it until step 108. Reverse-fold the edges together.



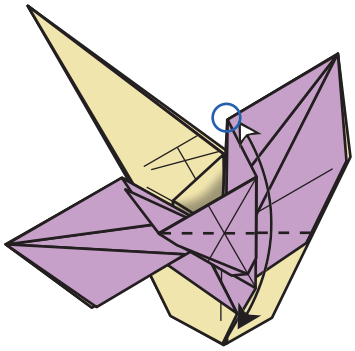
40. Open-sink using creases from steps 35 and 37.



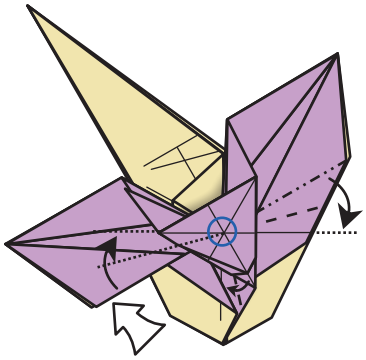
41. Reverse-fold the thick layers up and to the left.



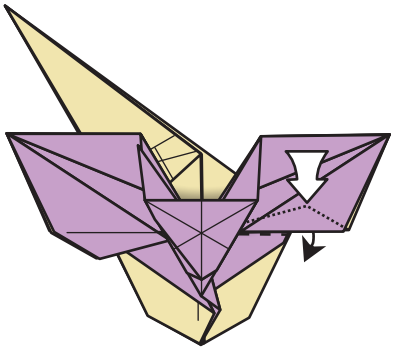
42. Flatten the central triangle and simultaneously swivel-fold the left flap using existing creases, so that it rotates anticlockwise.



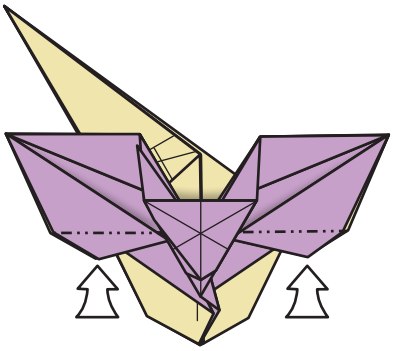
43. Fold the circled point to the bottom and unfold.



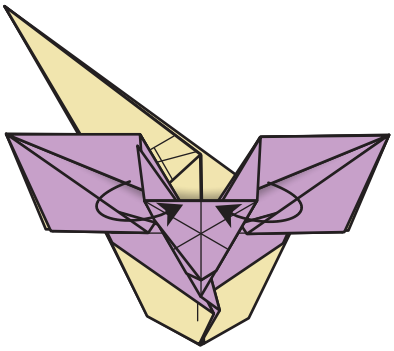
44. Twist the near layers, pivoting about the circled point. You will make three new angle bisectors where shown.



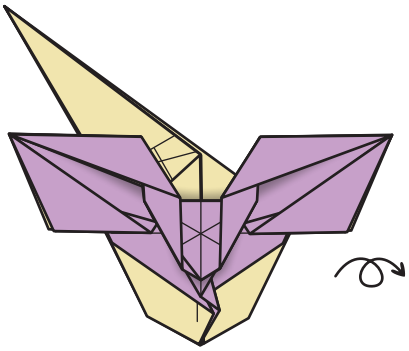
45. Reverse-fold the edge on the right down to match the left side.



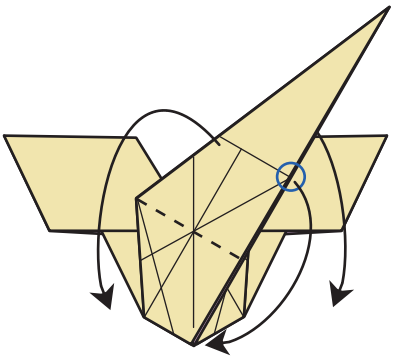
46. Closed-sink the corners upwards.



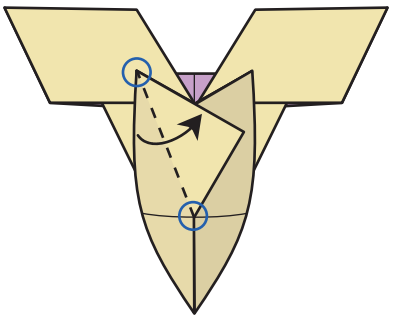
47. Carefully unwrap an edge on each side.



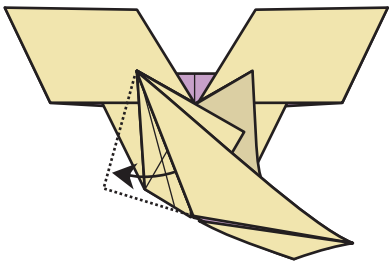
48. Turn the paper over.



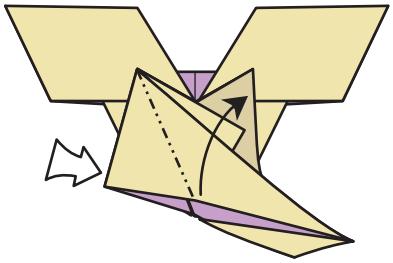
49. Outside-reverse-fold the flap using existing creases. The circled point goes to the bottom of the paper, and will become a concave vertex; the paper won't lie flat until after step 64.



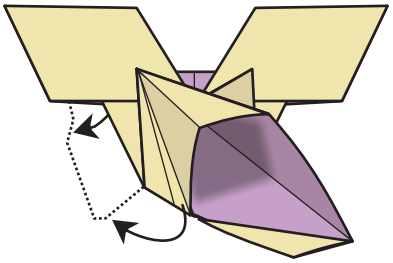
50. Fold the edge to the right along a new fold-line.



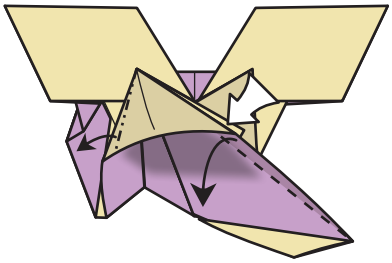
51. Carefully pull out the raw edge.



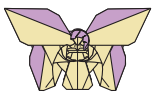
52. Lift the raw edge gently.

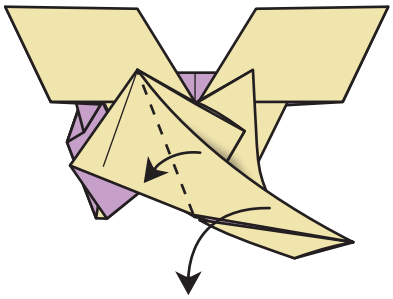


53. Unwrap the raw edge from the corner at the bottom, and fold the connected layers on the rear side of the paper to the left.

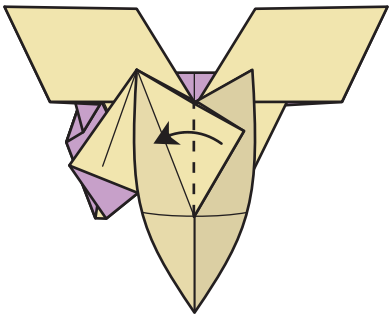


54. Flatten the raw edge by squashing it down and to the left.

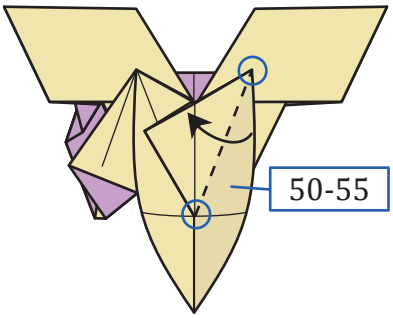




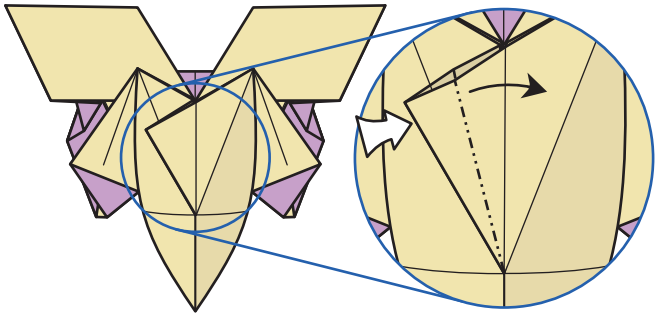
55. Fold the outer layers towards you.



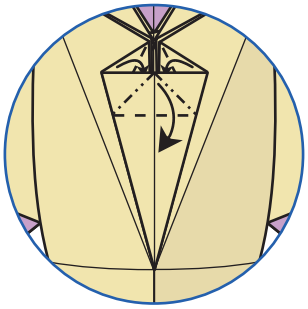
56. Fold the flap to the left.



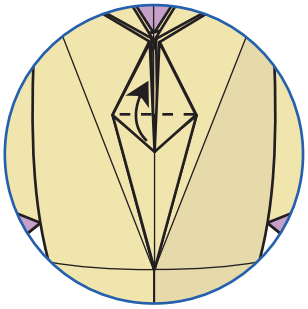
57. Repeat steps 50 to 55, flipping left and right.



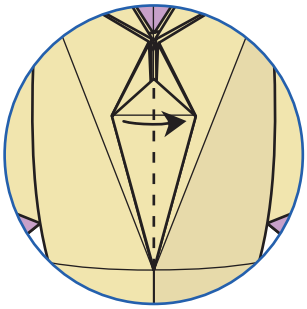
58. Squash-fold the edge.



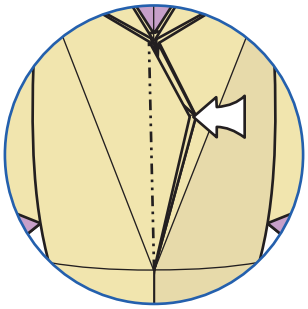
59. Petal-fold the edge down to make a point.



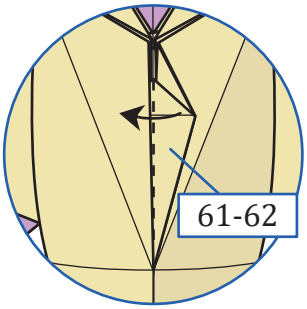
60. Fold the corner up.



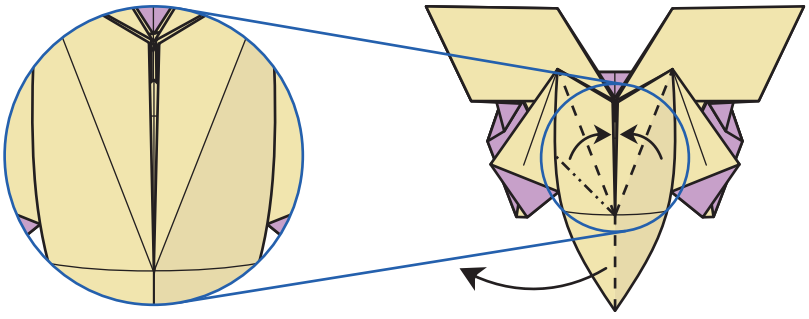
61. Fold one flap to the right.



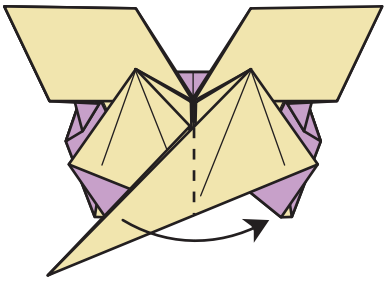
62. Closed-sink to hide the near corner.



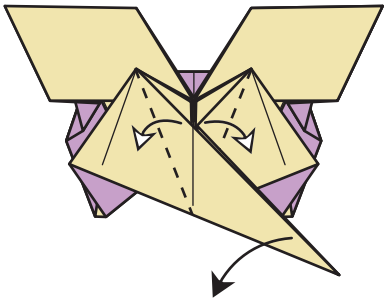
63. Repeat steps 61 and 62 on the right.



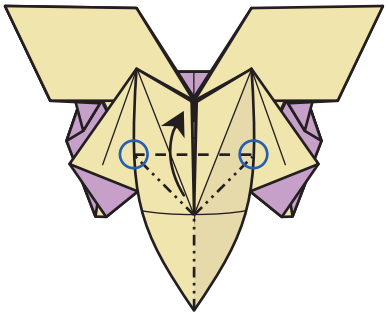
64. Bring the vertical edges to the centre and flatten the corner to the left.



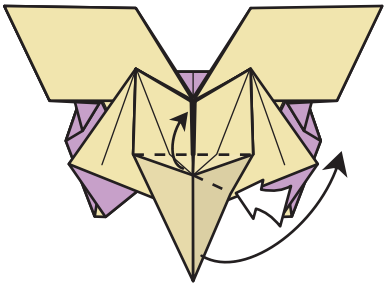
65. Fold the corner to the right.



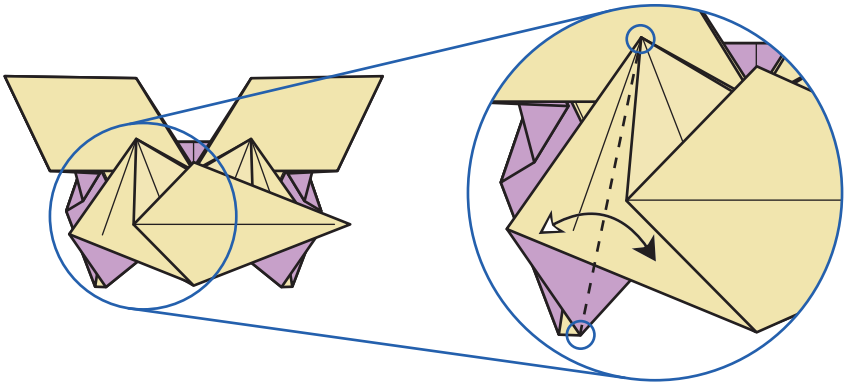
66. Unfold back to step 64. The paper won't lie flat until after step 68.



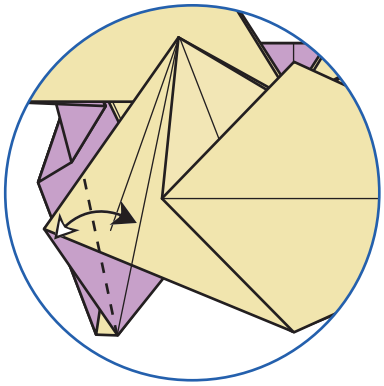
67. Invert the vertex of the **near layer only** by pushing it upwards. Use the mountain folds made in steps 64 and 65, and a new valley fold which connects the top of those creases.



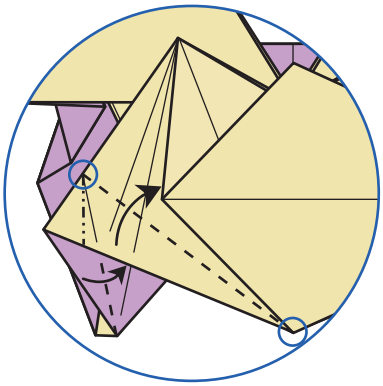
68. Flatten the long point to the right.



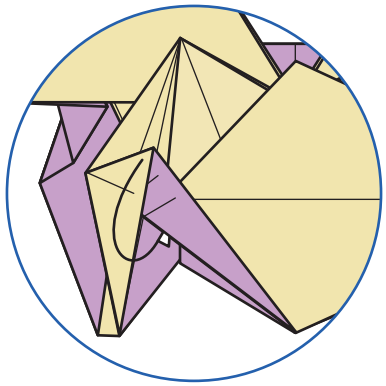
69. Fold between the circled points, then unfold.



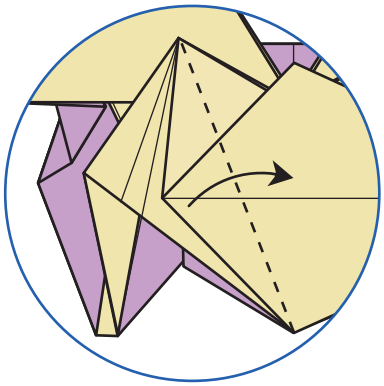
70. Fold an angle bisector and unfold.



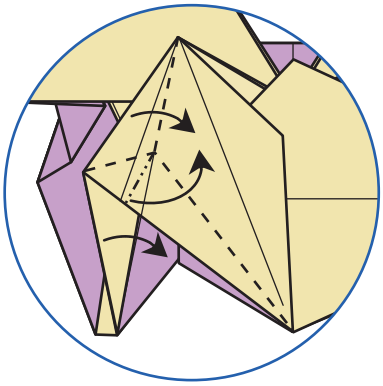
71. Swivel-fold the raw edge up using a new valley fold which connects the circled points, and the crease from step 70.



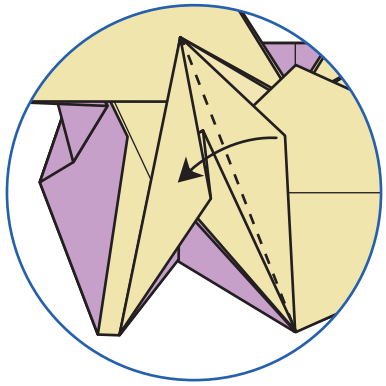
72. Fold the edge underneath by changing the new valley from step 71 into a mountain.



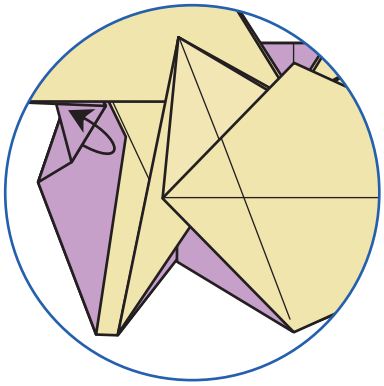
73. Fold one flap to the right.



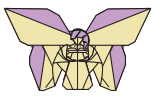
74. Rabbit-ear the near layer, which will bring the connected layers to the right too.

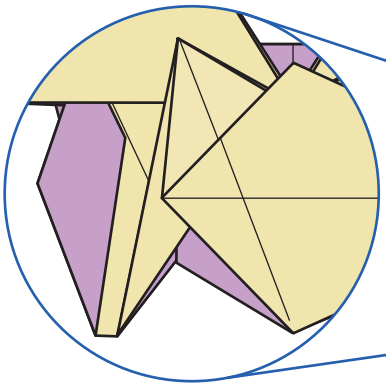


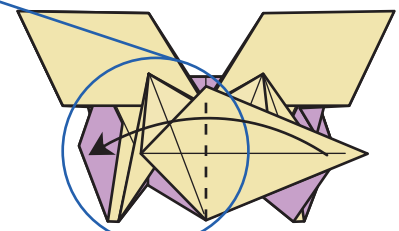
75. Fold one flap back to the left.



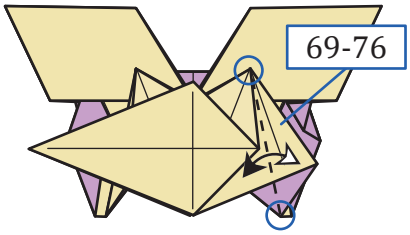
76. Wrap the coloured region around so that it is on the front. You may need to partially unfold the paper to achieve this.



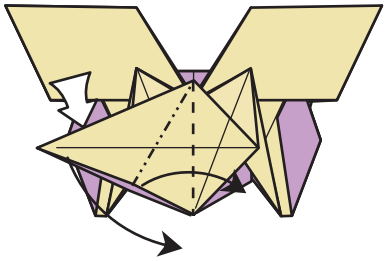




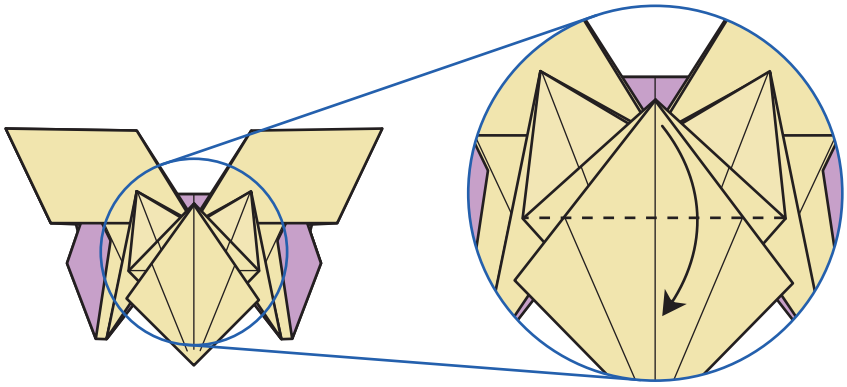
77. Fold the flap to the left.



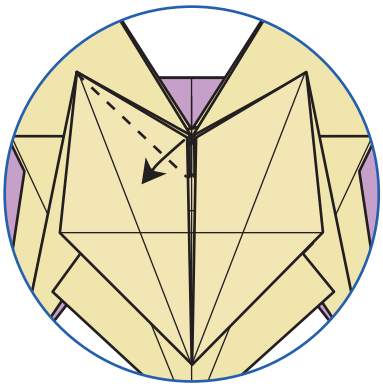
78. Repeat steps 69 to 76 on the right.



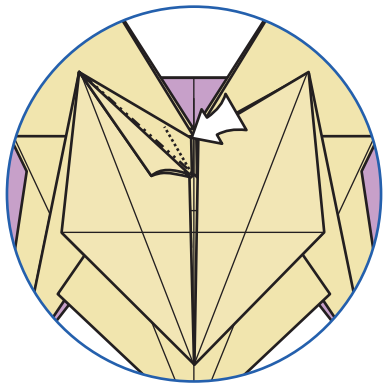
79. Squash-fold the flap.



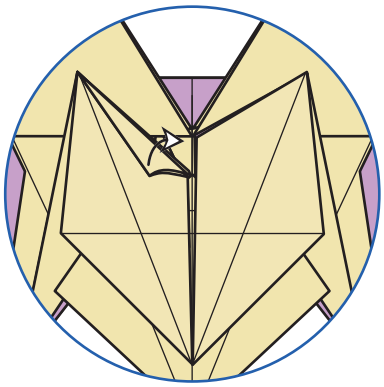
80. Fold one flap down.



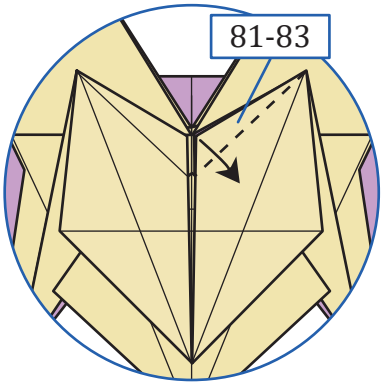
81. Gently fold the near flap down.



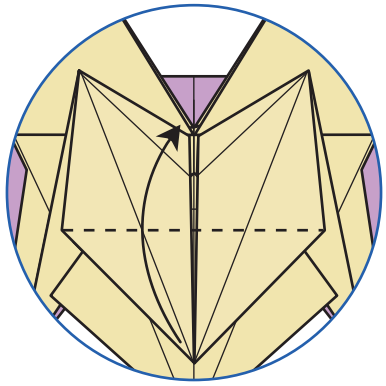
82. Reverse-fold the edge down and to the left.



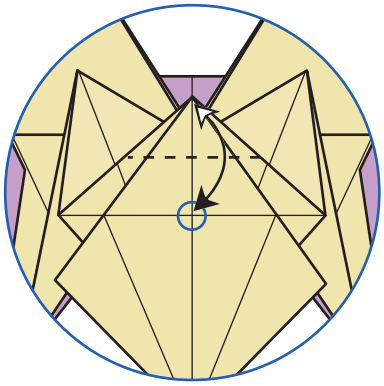
83. Fold the edge back up.



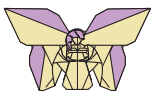
84. Repeat steps 81 to 83 on the right.

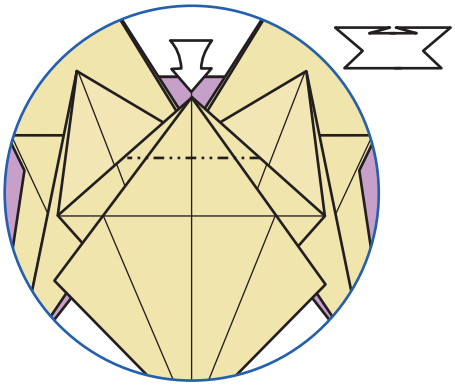


85. Fold the corner up.

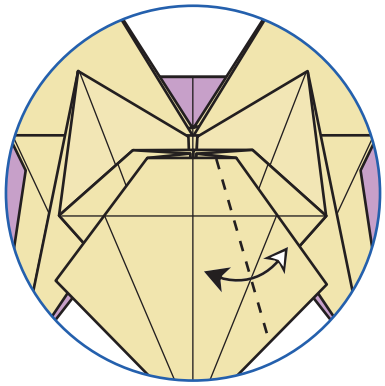


86. Fold the corner to the circled point, then unfold.

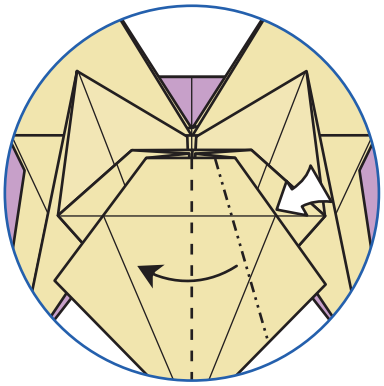




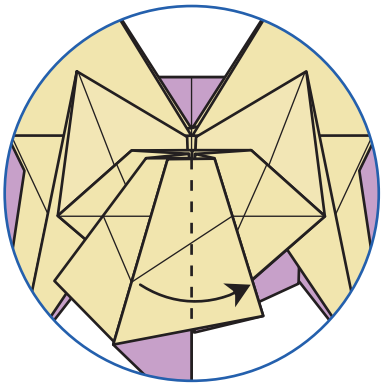
87. Mixed-sink the corner; closed on the far layer, but open on the near layers.



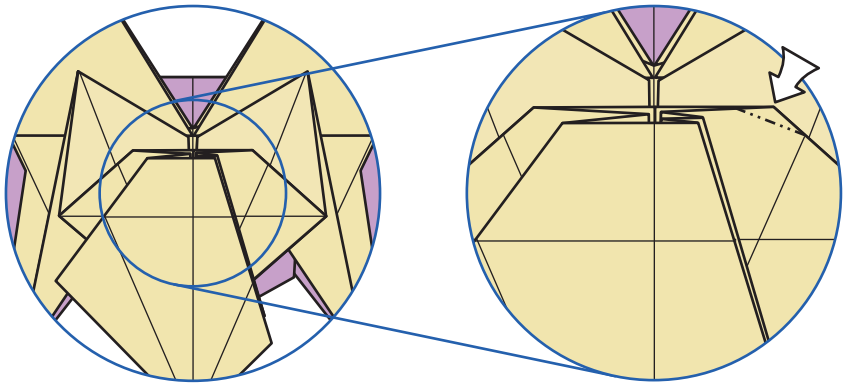
88. Fold and unfold.



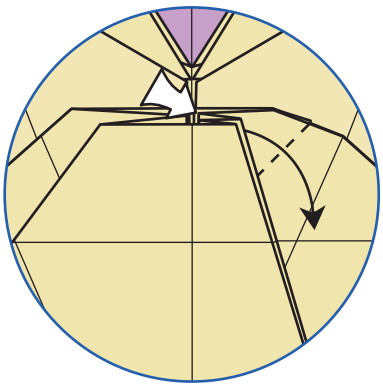
89. Spread-sink the edge.



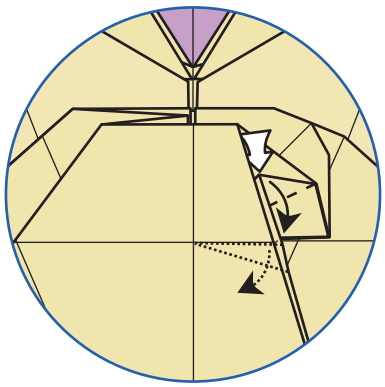
90. Fold the edge back to the right.



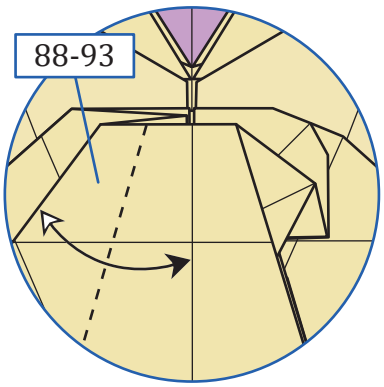
91. Open-sink the corner.



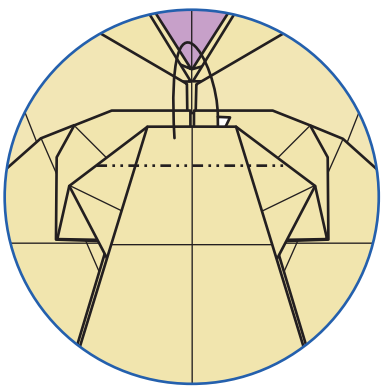
92. Reverse-fold the edges down to the right.



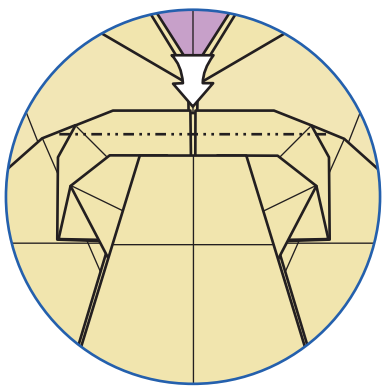
93. Swivel-fold the edge down. The location of the lower folds isn't important.



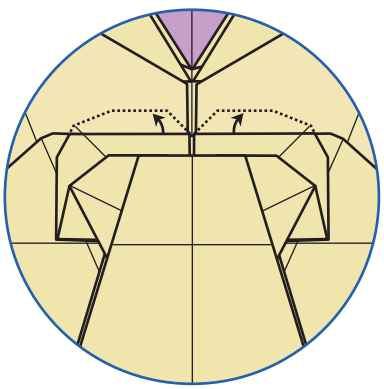
94. Repeat steps 88 to 93 on the left.



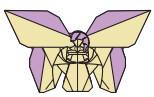
95. Mountain-fold the edge behind.

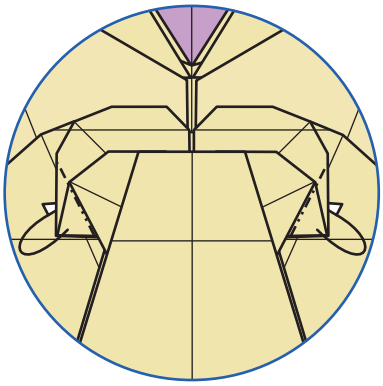


96. Closed-sink the edge, but only fold gently.

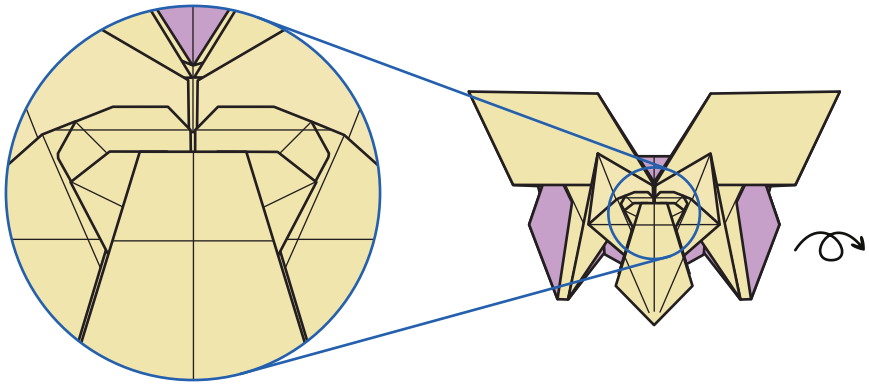


97. Carefully pull out the near layer on each side (but leave the middle part sunken). This will create new diagonal folds in the centre.

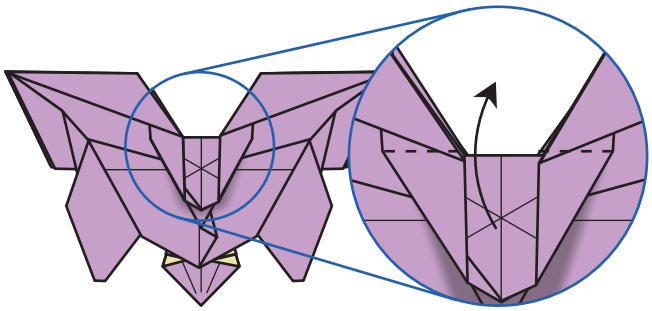




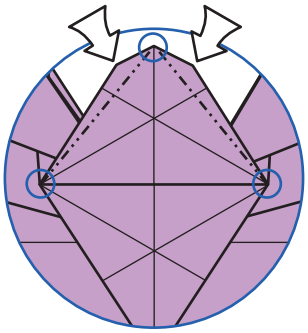
98. Mountain-fold the corners behind.



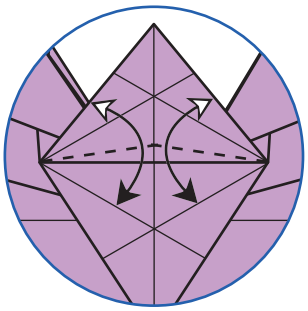
99. Turn the paper over.



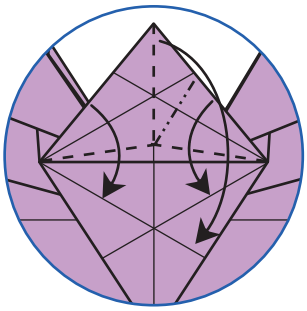
100. Fold the flap up.



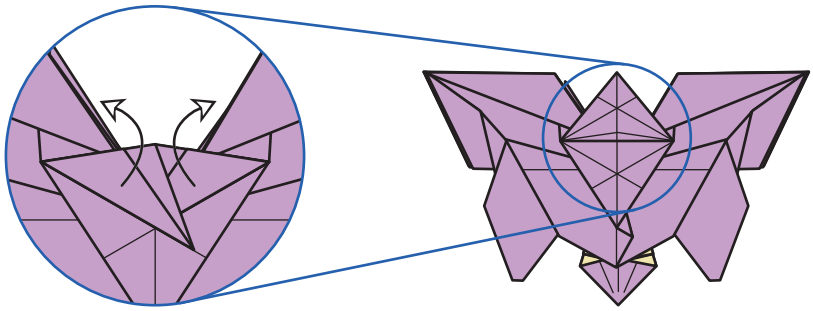
101. Push two edges behind using new mountain folds which connect the circled points.



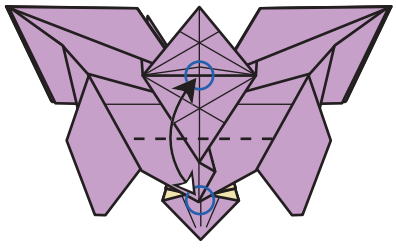
102. Fold an angle bisector on each side.



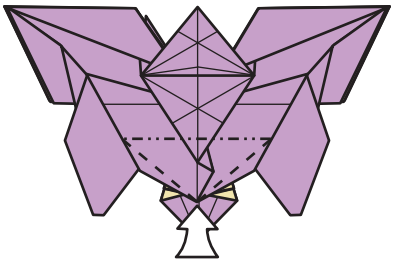
103. Rabbit-ear the corner using the creases you just made.



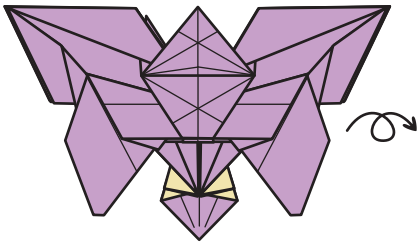
104. Take note of where the paper is; you will later need to use these folds in step 114. Unfold step 103.



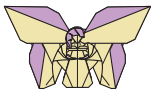
105. Fold the near flap at the bottom up to the circled folded edge, then unfold. The flap is connected to other layers – try to fold only through the near one.

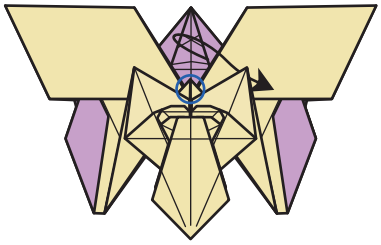


106. Sink using the creases you just made: the near layers and far layers are closed, the side layers are open. The surrounding layers restrict some of the folds of the sink, and will naturally make the corner sharper.

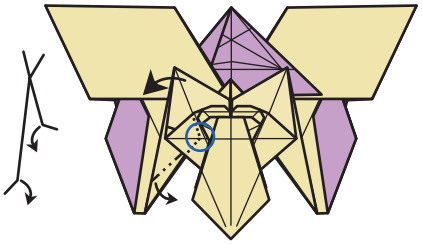


107. Turn the paper over.

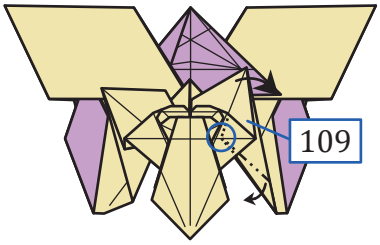




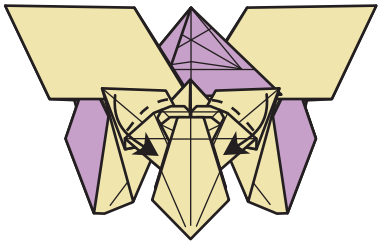
108. (You can now ensure that the circled corner sunk in step 106 is neat.) Carefully pull out the raw corner and tuck it under the flap, as shown.



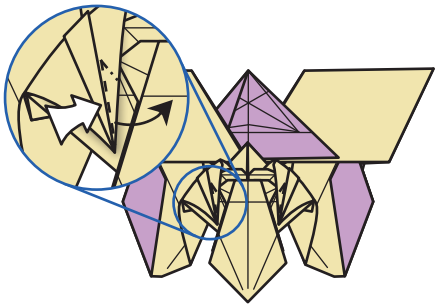
109. Twist the indicated region anticlockwise, rotating about the circled point, as shown. Some internal layers and the far layers (from the reverse fold in step 82) will need some readjusting so that the paper can lie flat.



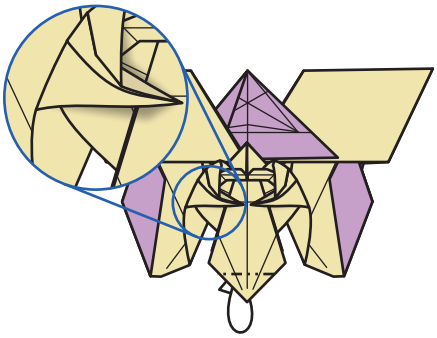
110. Like this. Repeat step 109 on the right.



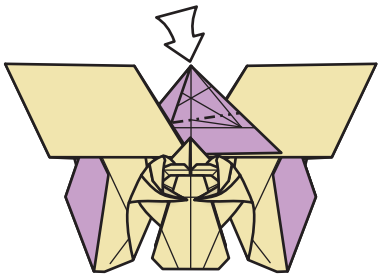
111. Fold the arms down using gentle curved folds.



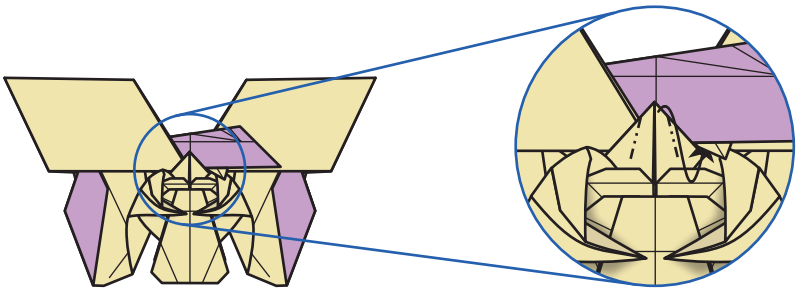
112. Make the arms three-dimensional at the elbows, and bend the forearms towards the centre of the paper.



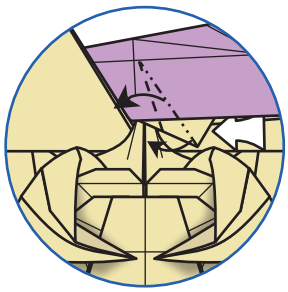
113. Mountain-fold the raw corner behind.



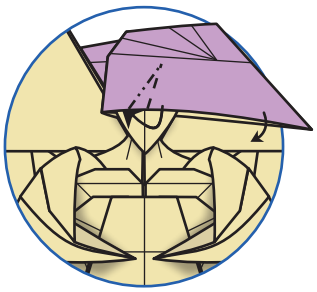
114. Sink the corner at an angle using folds noted in step 104, so that it ends up off-centre. The sink is open at the raw corner, but closed on the far layers.



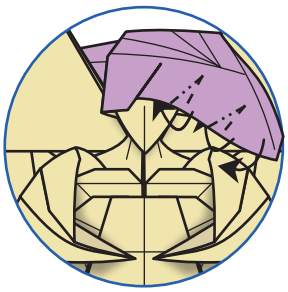
115. Curl the white region so that it becomes like part of a cone, and tuck it underneath the corner that you just sank, as shown. The region around the head won't lie flat from now on.



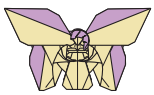
116. Squash-fold the corner to make the chin.

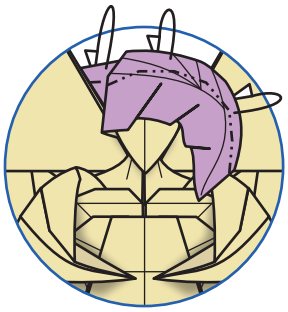


117. Pleat the paper and twist the raw corner down.

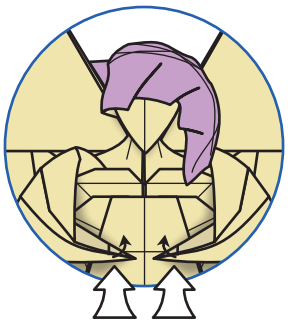


118. Pleat the paper twice more to form the rest of the hair.

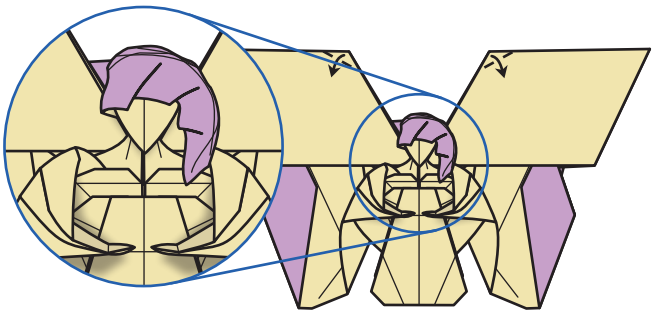




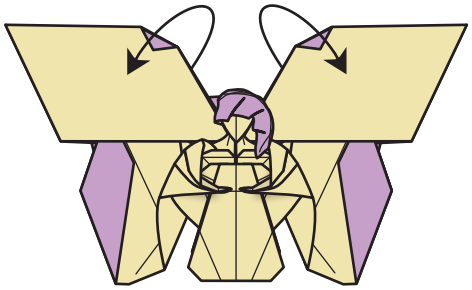
119. Fold the top edge behind and shape the top of the head and hair.



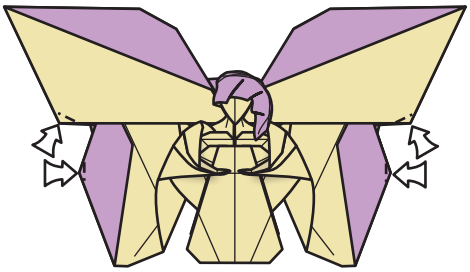
120. Curl the tips of the arms to suggest hands.



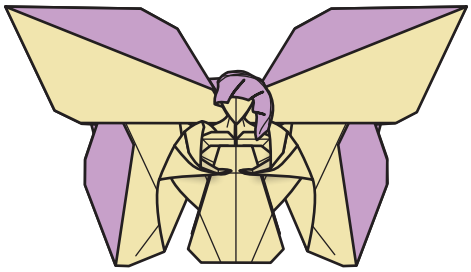
121. Valley-fold the two inner corners of the forewings slightly.

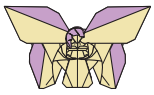


122. Carefully wrap the edges from the back around to the front.



123. Closed-sink four corners to make the wings rounder.

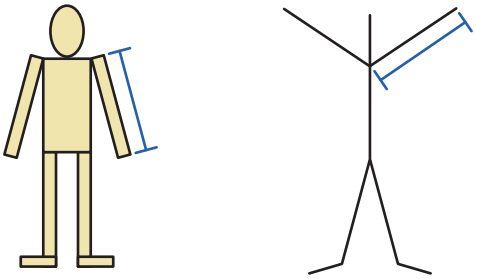




Tree theory

Many origami designers use tree theory to create their own models. If you haven't come across tree theory before, I'd recommend that you read something more extensive on the topic to make the most of this section, but I'll give a brief summary below as a reminder.

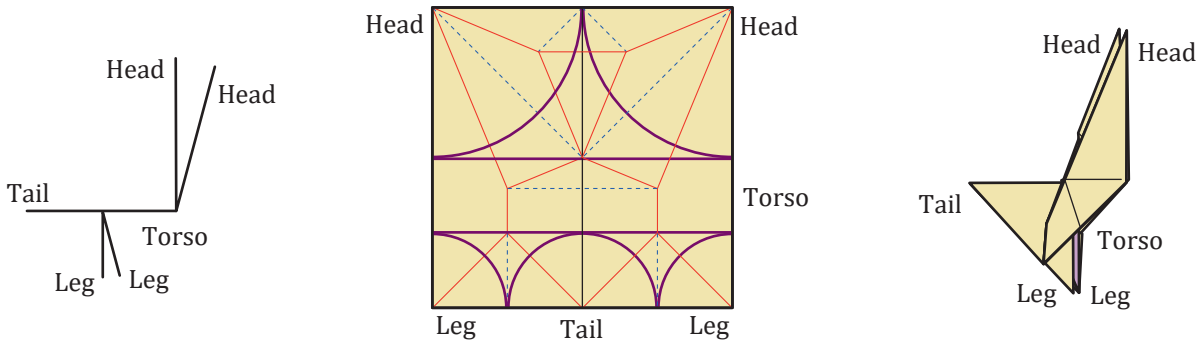
When designing a model, the aim is to fold a flap for each feature of a subject, and to do that, we need to know the size and position of each flap. Tree theory simplifies this design process by compressing information about a subject into a stick figure called a **tree**. Each tree is comprised of **edges** (the lines) and **vertices** (the points at the two ends of each edge). This reduces the number of dimensions of each feature down to one – a single line. The length of each edge in the tree needs to be the same as the length of the feature (relative to the other features).



The length of an edge in the tree is the same length in the subject.

Next we need to work out how much paper each edge of the tree will use up on the square. An edge that is only connected to the tree at one end (e.g. an arm) is called a **leaf edge**, and the unconnected vertex is a **leaf vertex**. Leaf edges can be represented on the paper by a circle (often we only show the part of the circle which intersects the square): the centre of the circle will be the tip of the flap in the folded model, and the radius of the circle is the length of the flap. Meanwhile, an edge that is connected at both ends (e.g. a torso) is a **branch edge** and can be represented by a strip of paper of constant width called a **river**. The width of the river is the length of the edge in the tree, and the two banks of the river are the ends of the edge in the tree.

If we arrange these circles and rivers compactly within the square so that circles and rivers touch (without overlapping) according to their adjacency in the tree, then we get a **circle/river arrangement**. This arrangement can be folded into a base with all the desired flaps. Arrangements are called **efficient** when the folded model is large relative to the starting square and the most efficient arrangements are **optimal**.



Left: Tree for the Two-headed Goose.
Centre: Crease pattern of the Two-headed Goose showing circles and rivers.
Right: Folded base of the Two-headed Goose.

The problem with tree theory

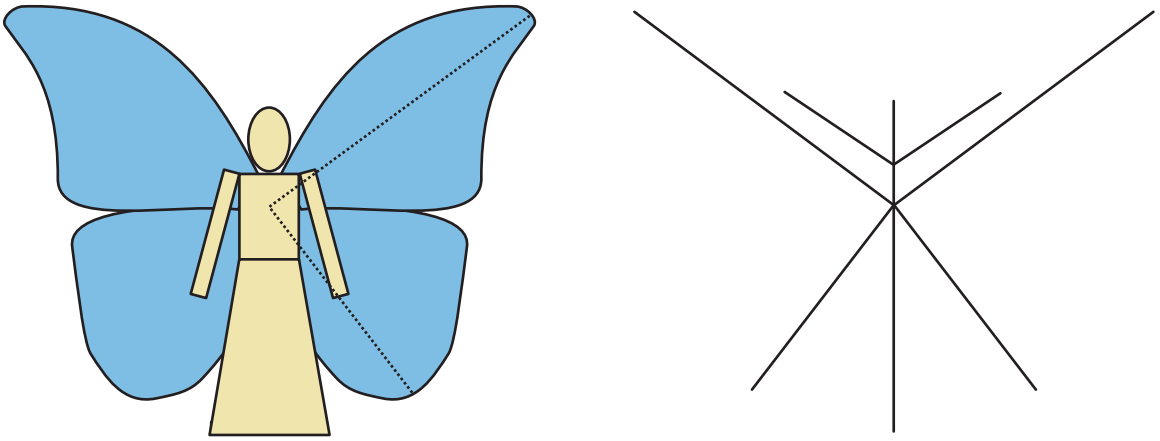
There are a few things that tree theory cannot do, but in my opinion, the biggest issue is that we have no control over the width of flaps. Efficient arrangements tend to make thin flaps. This is because flap width occurs only as a result of excess paper in the gap between flaps. This consequence of efficiency can be a good thing for spindly subjects, but for a subject with broad features, the desire to get a wide flap actually contradicts the principle of efficiency.

This is no surprise given the method of making a tree – we remove all flap width when we make each feature into an edge. Therefore the whole process of arranging circles only guarantees that we can make the tree, not the subject itself. Designers often get away with this approximation because paper can't have zero thickness like a line; there will always be some width to the flap, and much of the time this leftover amount of paper is sufficient. For example, the folded base of the Two-headed Goose made from the circle/river arrangement on the previous page conveniently forms the shape of the body with no extra work.

Most of the time, when a tree is a poor approximation of the subject, tree theory leaves us unable to design around this issue in a methodical manner. So in this section I'll explain a new method (as far as I know) that expands tree theory to account for flap width using the example of my model, Psyche.

Canopy theory

As ever, it's easiest to begin with the example in question: the aim is to make a human figure with butterfly wings. Attempting to draw a tree for this subject immediately reveals a conundrum: butterflies have four wings in total (two forewings and two hindwings), but should we connect the forewing and hindwing on each side to make one large flap or make them separate? And in either case, how long should the corresponding edges in the tree be? When we attempt to make a tree, the result bears little resemblance to our desired subject, so we might start to wonder if these are even the right questions to be asking.



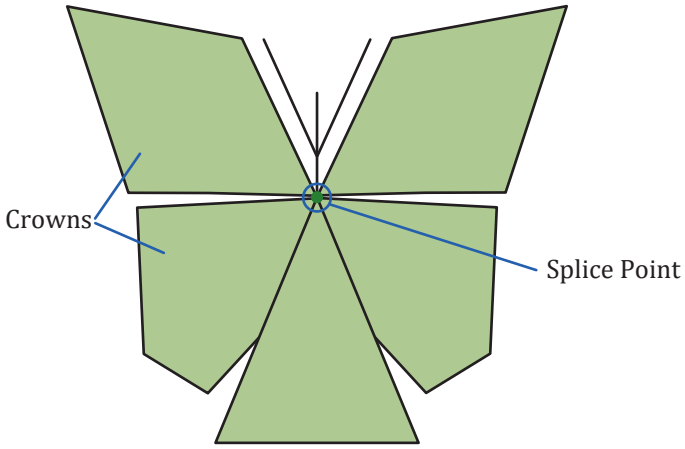
Left: Psyche, our subject. Right: A tree where the length of wing flaps are the longest distance from the hinge to the tip of each wing. This is a poor approximation for Psyche: normally we can recognise the subject from the tree, but we seem to have created the tree for a monster instead of a beautiful goddess.

The problem lies with the approximation to a one-dimensional line, so the natural fix to consider is to approximate features with two-dimensional shapes instead. Origami fold-lines are all straight line segments (if you want to be a purist with references for each fold), so curves are probably not a good idea; we should use polygons. We should also make sure each polygon is **convex** – all angles are at most 180° – because it's not possible to fold an angle greater than 180° from one contiguous region of paper.

We needn't complicate things unnecessarily though: where a line is a suitable approximation for a feature, like with each limb, we should still use an edge. Any new additions need to be made in such a way that they are compatible with existing theory so that we can make use of our existing methods.

Enhanced trees

Rather than making a stick figure approximation, we'll use a slightly more complex mathematical object: a tree diagram but with some polygonal regions too. We ought to give this object a name, and it would be nice to continue the flora-based nomenclature. So I'll call this more general structure a **plant diagram** (or **plant** for short). In contrast to barren trees, these objects have wide areas reminiscent of foliage – I'll call each of these regions a **crown** and colour them green. Each crown is attached to the plant diagram at a **splice point**, and the process of adding crowns to an existing tree/plant diagram is **splicing**.

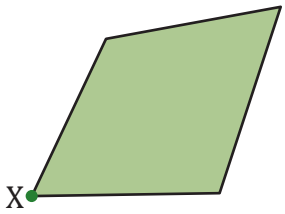


A plant diagram for Psyche, with five crowns which approximate two forewings, two hindwings, and the dress, respectively. For the time being, these shapes are simply examples while we are still exploring what's possible with plant diagrams – we may end up adjusting these later if we need to.

We have a representational challenge here; while trees are easy to draw because the edges can always be moved out of the way, so that they don't intersect with other edges, crowns in a plant diagram don't necessarily fit in the right place on the page without overlapping. For Psyche's plant diagram, we'll need to keep in mind that there is a gap between the hindwings and dress in the third dimension. Speaking of the third dimension, I'll also note that any curved sections of the final model will require more paper than is depicted by a two-dimensional projection of a subject. For example, the dress might be better modelled by a cone or a cylinder, so we might want to make the dress's crown wider later on.

Crowns

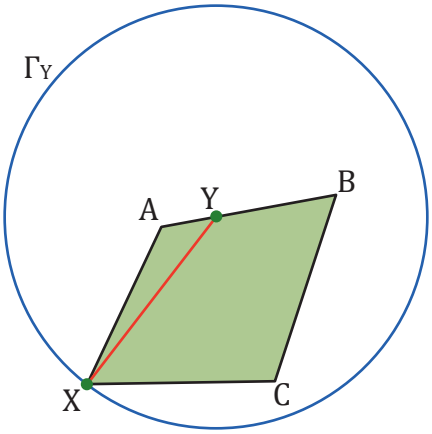
Let's consider the paper needed for just one crown; I'll pick the top-right forewing as an example. The most important question to answer is: how much paper will this crown take up on the square? For the sake of ease, we may assume that the crown will be one contiguous area of paper (because if this isn't desired for any reason, we can always just divide the paper into multiple convex subpolygons and consider those instead – see page 68).



Crown for the top right forewing. The splice point of the crown is at X.

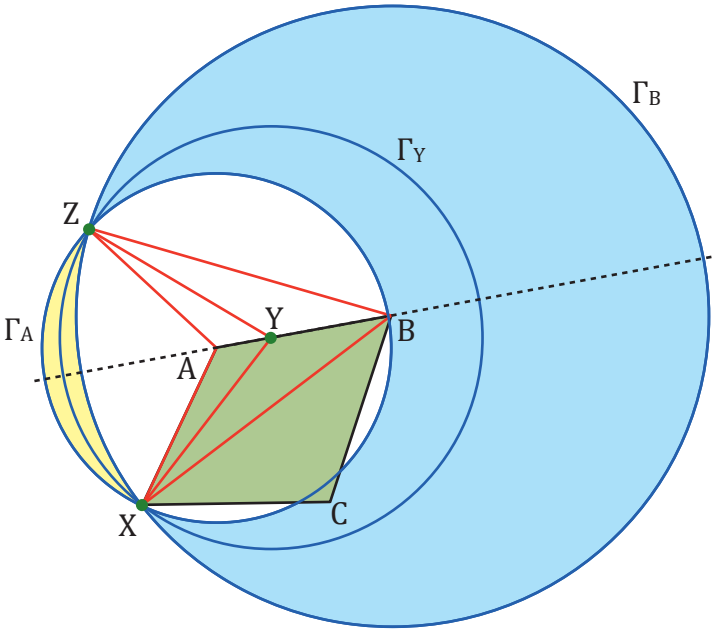
So far so easy, but what about the paper outside the crown itself? Paper which is close to the boundary of the forewing's crown will likely need to be in the flap for the forewing, but how close exactly? In tree theory, we form circles around leaf vertices because a circle is the locus of all points within a certain distance (the flap length) of the flap tip. We'll use the same idea here, but rather than considering just the flap tip, we'll look at every point along the entire boundary of the crown.

As an example, consider an arbitrary point Y along the line segment AB. The line XY is shown in red. Any paper which is not going to be on the forewing must be at least distance XY away from Y, because it can only be connected to Y via the splice point at X. This forms a circle, Γ_Y ('gamma Y'), around Y. So put another way, any point within this blue circle is too close to Y to be part of any other other feature.



The crown for the forewing, with a circle centred at Y which has a radius equal to the distance XY.

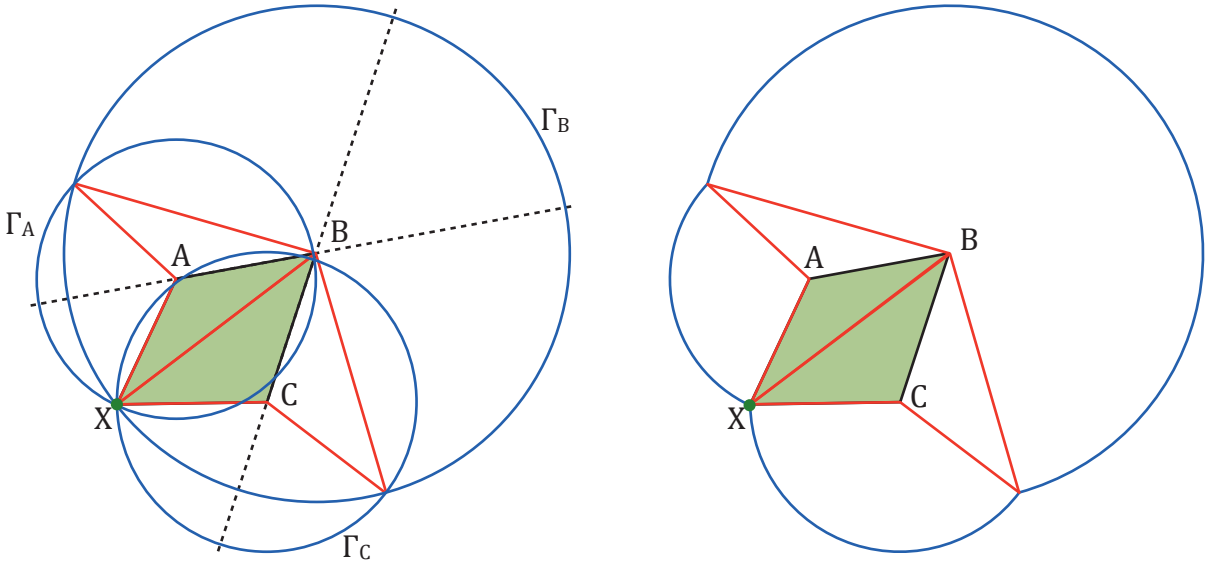
The same argument applies not just at Y but at every point on the crown's boundary. In particular, let's also consider the circles centred at the vertices A and B; call these Γ_A and Γ_B respectively. The three circles drawn so far all pass through another point, Z. This isn't a coincidence – all of these circles are symmetric about the line AB, and so Z is the reflection of X in the line AB.



All circles centred along AB which pass through the splice point X also pass through Z. The circle centred at Y is entirely contained in the two shaded 'lunes'.

The minor (smaller) arc XZ of Γ_Y is sandwiched between the minor arcs of Γ_A and Γ_B: this area is called a **lune** and is shaded in yellow above. Similarly, the major arc XZ of Γ_Y is contained in the pale blue lune between the major arcs of Γ_A and Γ_B. These two facts together mean that the whole circle centred at Y is contained within the union of the circles Γ_A and Γ_B. Y was chosen arbitrarily, so it is sufficient to consider only the circles Γ_A and Γ_B instead of looking at every point along AB. And this argument doesn't just apply to AB but to each of the other edges of the crown; we only need to look at the circles centred at the vertices of the crown.

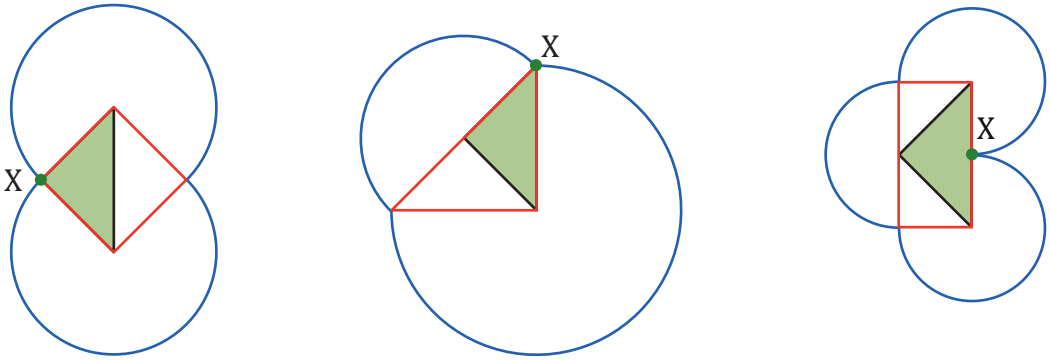
I'll call the union of the circles made by this process the **canopy** of the crown. If we'd used our original stick figure approximation for the forewing we would have used only the circle Γ_B. It's surprising to me how little extra paper we need to add to go from Γ_B to the whole canopy.



The union of Γ_A, Γ_B, and Γ_C make the canopy of the crown.

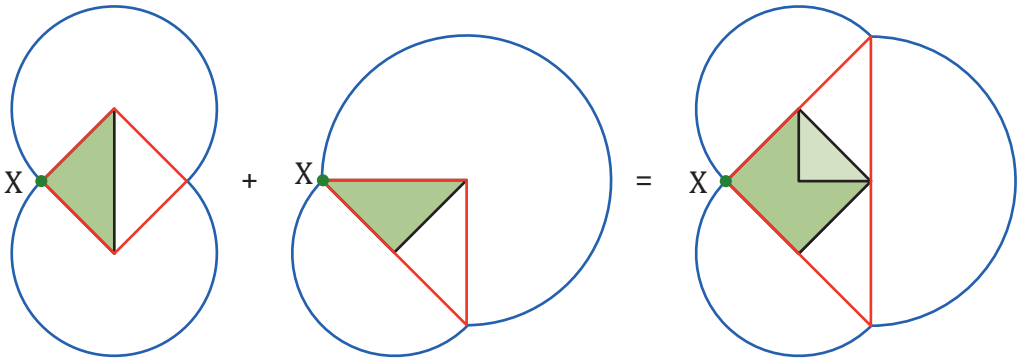
Other crown shapes

Let's explore canopies by looking at some other simple crown shapes to observe some general properties.



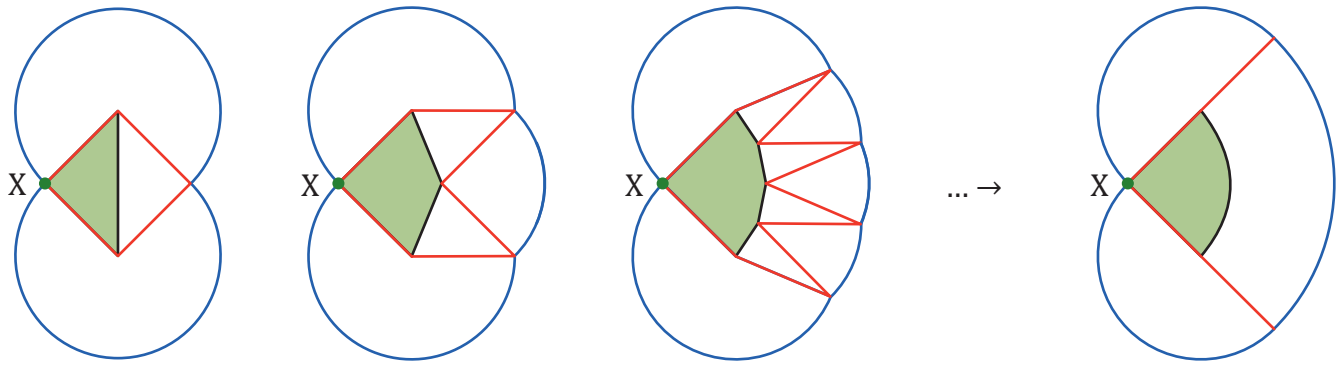
Canopy shapes for a 45-90-45 triangle. Observe that the canopy's shape depends on the location of the splice point, and that the splice point doesn't need to be a vertex of the crown.

If we take any two crowns and overlap them at their splice points, we obtain a new canopy which is the union of the two individual canopies. However, the new crown might not be convex. If this happens, the new crown is the smallest convex polygon which contains both original crowns – this shape is called the **convex closure**. We can see an example of this using the first two crowns above.



Adding canopies with the same splice point: take the convex closure of the crowns, and the union of the canopies. This is a commutative operation (the order doesn't matter), so this works for adding any finite number of crowns.

We can also take a limit of canopies to obtain a union whose crown isn't a polygon. For example, in the sequence of crowns below, each crown has successively more vertices which are all the same distance from the splice point. The limit of this process is an arc of a circle. This is useful because calculating distances with circles is easier than with polygons, so this process can simplify computation when it comes to finding an arrangement (whether done manually or by an actual computer).



The union of an infinite number of canopies with the same splice point can obtain a crown with a curved edge. Notice that the region on the right of the canopy is very much like a river.

Splicing

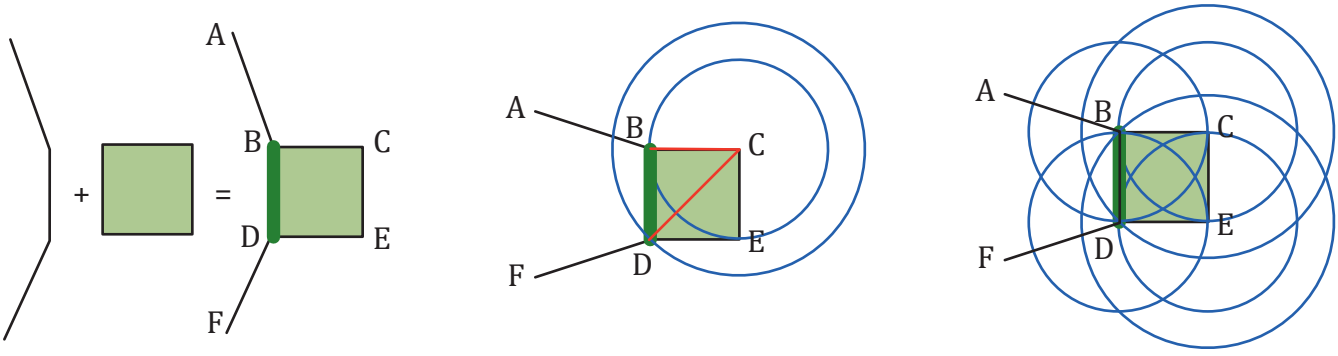
In tree theory, edges must meet at points because that's the only type of intersection between lines. But in plant diagrams, a crown can intersect another feature along a whole line (or line segment if we're being precise). We'll call such a line the **splice line** of the crown. There are two separate cases to look at: a crown intersecting an edge of the tree or a crown intersecting another crown.

Crown/edge splice lines

This type of splice line shares a property with branch edges; they partition the points on the plant diagram into two categories, depending which side of the splice line they are on.

The example below is a plant diagram which is formed by splicing a simple tree with a square crown along the edge of one side of the square. As before, we'll draw circles centred at the vertices of the crown, but now we need to include multiple circles for each vertex; one circle will pass through one end of the splice line, the other circle will pass through the other end of the splice line.

For example, in the central image below, there are two circles centred at C; one passes through B, the other passes through D. Two circles like these need to be drawn for each vertex (including B and D, though as these are the ends of the splice lines themselves, their smaller circles are of radius 0, so we can omit those).

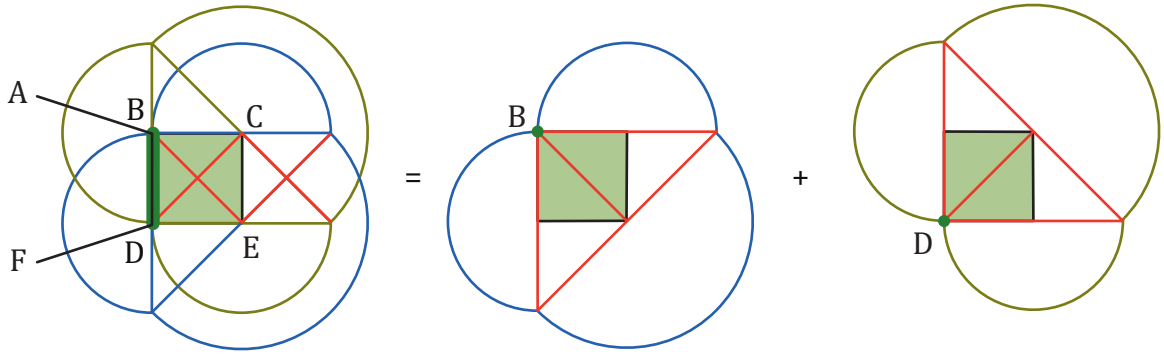


Left: Plant diagram formed by splicing. Centre: Circles drawn around C. Right: All circles drawn.

Admittedly, it's a bit of a mess. But we can start to see what's happening if we categorise the circles by which end of the splice line they pass through – these are in different colours below.

What's happening is that from the perspective of the leaf vertex A, the relevant end of the splice line is at B. Meanwhile from the perspective of the vertex F, the relevant end of the splice line is at D.

So we've just got two canopies superimposed – these are the canopies of the square from the previous page added together. But this time, we have two different splice points.

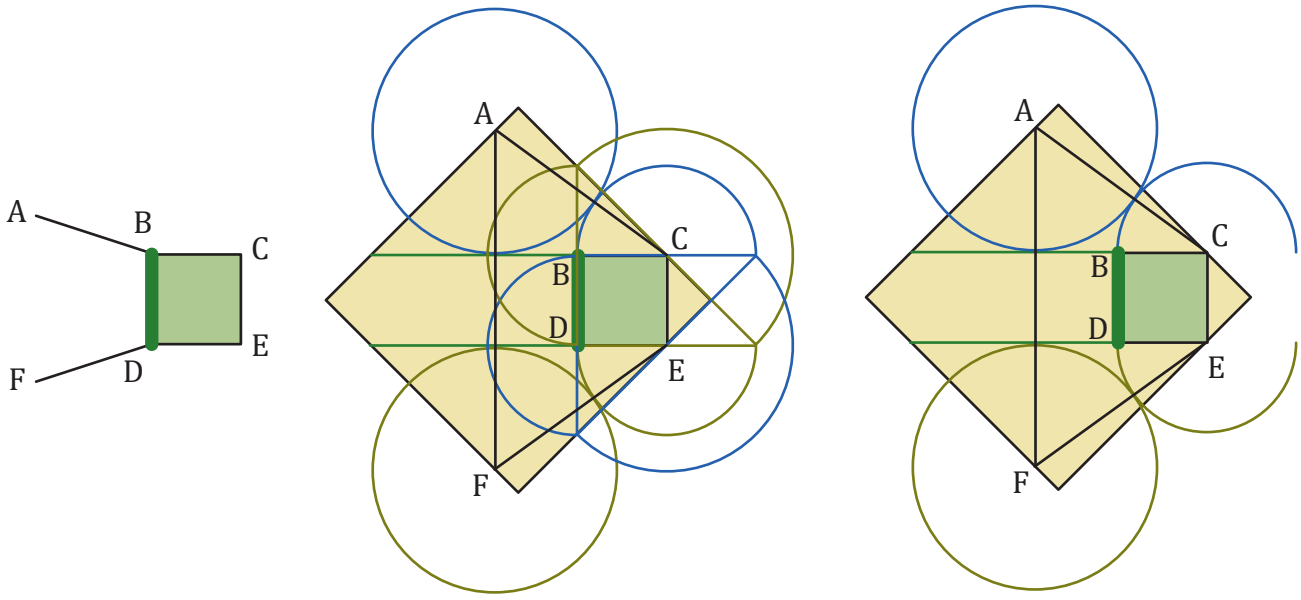


The canopy for this square crown with a splice line BD is made by combining the canopies with splice points B and D respectively.

Let's try to get this canopy in some sort of circle/river/canopy arrangement. Of course, we still need our circles for A and F, and as usual the centres of these circles need to be on the paper. These circles are coloured according to the nearest end of the splice line, which lets us separate features with a simple rule: circles of the same colour cannot overlap.

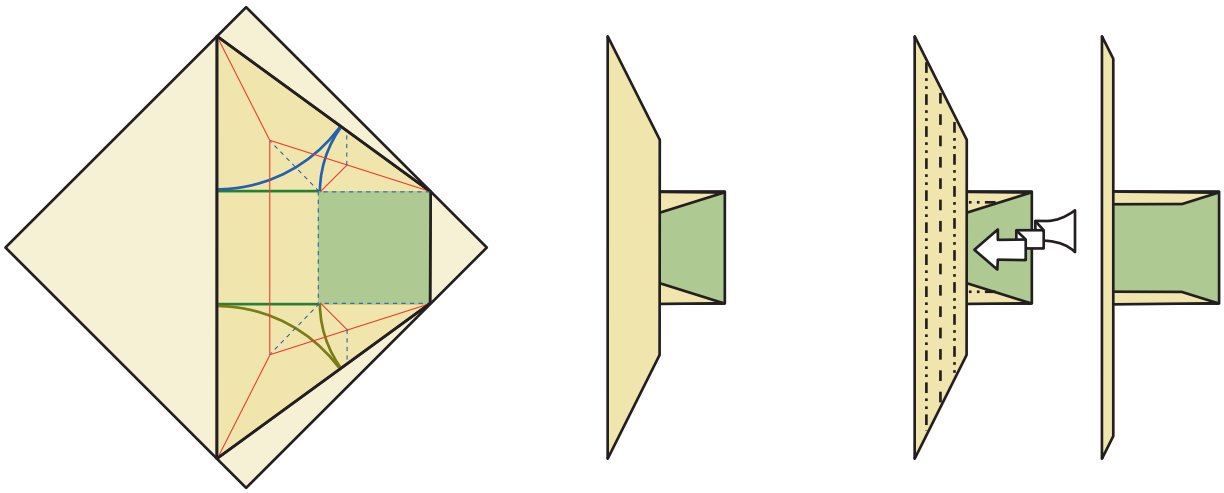
As for the canopy, we need to make sure that the whole crown lies on the paper. Also, the splice line BD is a river that separates A and F, so we mustn't forget this in our arrangement.

Clearly A and F must be far apart, and the best way to do that is to place them at opposite raw corners. But we can actually find a more efficient arrangement if A and F are not quite at the raw corners. A little playing around should convince you that the arrangement below is the best we can do.



Left: Plant diagram. Centre: An arrangement for this plant diagram using a canopy. Right: The same canopy, but with several arcs and lines removed for clarity.

All we've done so far is theoretical, but does this actually work? The easiest test is to just have a go at folding it. If you do, you'll find that it does work, perhaps much more simply than you would have imagined. A crease pattern for this arrangement is shown below.



Left: Crease pattern. Centre: Folded base.
Right: Sinking gets us arbitrarily close to our desired shape.

Or at least, it sort of works. We get exactly the same problem that tree theory gives us in plan models (where two flaps are separated by an axis): in order to obtain the theoretical lengths on the plant diagram we need to open-sink the central ridge in and out an infinite number of times. This is rather impractical, so, as with tree theory, we observe that we can get arbitrarily close to our desired shape with a sufficiently high (finite) number of sinks.

It should actually be no surprise that the plant diagram is foldable: viewed another way, this arrangement is a basic tree with a strip grafted down the centre – as long as the paper on either side of the central flap is symmetric, then the graft adds the required width. This happened because the square crown has parallel sides, but in general this wouldn't be the case.

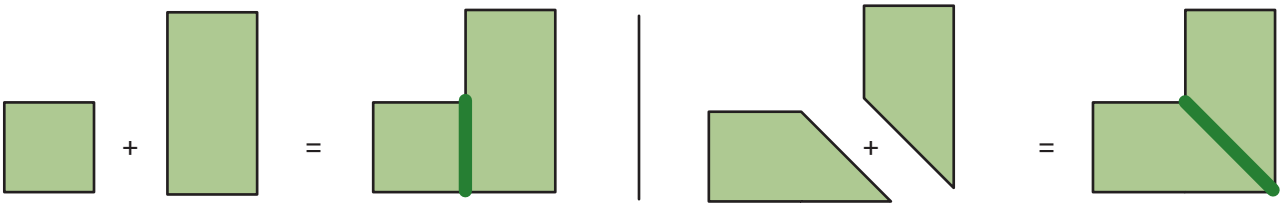
So maybe we just got lucky here – and of course you cannot prove by example anyway. Indeed, nothing we've done so far gives any method for verifying that a given arrangement is foldable, even less so an algorithm for generating a crease pattern (both tasks are well beyond the scope of this book). What we have achieved with canopy theory is a minimal condition; we need at least the area of paper in the canopy in order to fold a contiguous polygon, but perhaps more paper is needed.

But then, how useful is this incomplete analysis? By analogy, consider arrangements found with the circle method from trees (without canopies). An exact optimal arrangement in tree theory is rarely the best arrangement from the perspective of a folder (because of the lack of references, unusual angles, no accounting for colour changes, etc.), but it is very useful for identifying roughly where various features will fit best within the square. We can then massage the points to get nicer references and easier folding sequences. Likewise, canopy theory shows the location where large crowns fit well, but then the designer ought to work out a cleaner arrangement with a pleasant folding sequence to finesse the design anyway. So from a practical perspective, more analysis won't help us make nicer models. (Of course, there are other reasons to develop origami theory, so please do pursue canopy theory if you are keen!)

Crown/Crown splice lines

We've dealt with the easy case where the splice line is an edge of the tree. But there's a fundamentally different type of scenario: when we want to stitch two different crowns together along a line.

One reason we might want this is to obtain **concave** polygons – polygons where at least one angle is more than 180°. A concave polygon can be spliced together from smaller polygons in multiple different ways, so there is a lot of flexibility here.



Two examples out of an infinite number of possibilities for making the same concave polygon from multiple convex polygons.

We also might want to split a convex polygon to add an edge or a crown in the plant diagram which emerges from the middle of a crown. For example, we can add an edge to the centre of an equilateral triangle.

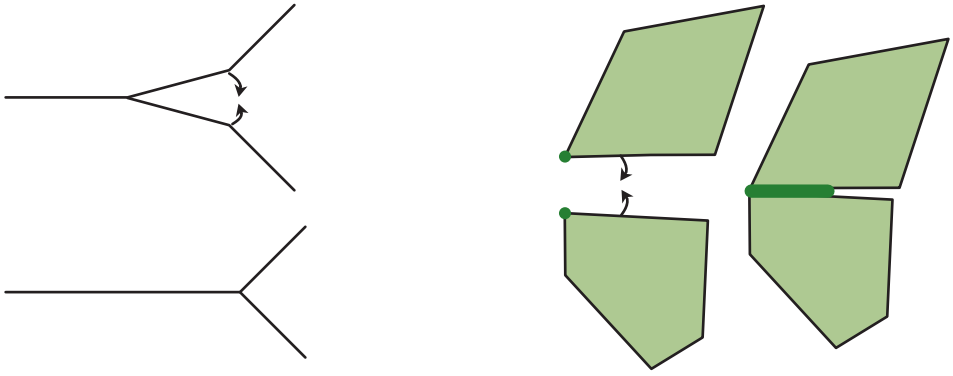
Left: How can we add a new edge to the centre of this crown?
Right: Split the crown into two regions which are spliced together.

This sort of solution might not be desired though, because we cannot reconnect the bottom pieces together. Another method here would be to bring the edge into the centre by folding a larger crown, as shown below. In any case, we have to account for whether the new edge should come from the front or back of the polygon – a type of consideration that doesn't appear in tree theory.

Folding a crown is another option for adding an edge to the centre of a region.

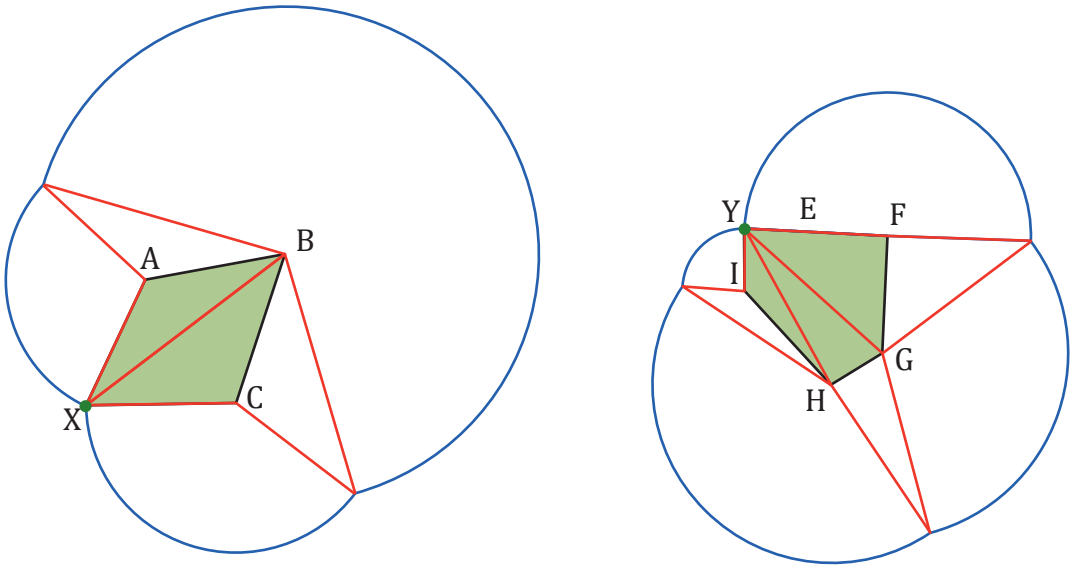
Subcanopies

We can use a crown/crown splice line to answer the question we faced several pages ago about whether we should have separate flaps for forewings and hindwings. We can add a splice line between two crowns, which is a good idea because connecting crowns together should use less paper than making each individual crown. This is a compromise between anatomical accuracy and efficiency, and we have control over the exact length of the splice line to give more weight to whichever of these origami virtues is more important to us.



Left: Combining two separate edges into one river reduces the area of paper the tree will need.
Right: Similarly, connecting two crowns along a splice line reduces the total paper needed.

So what does this look like on the paper? Let's start by drawing the canopies for both crowns with a single splice point for each.

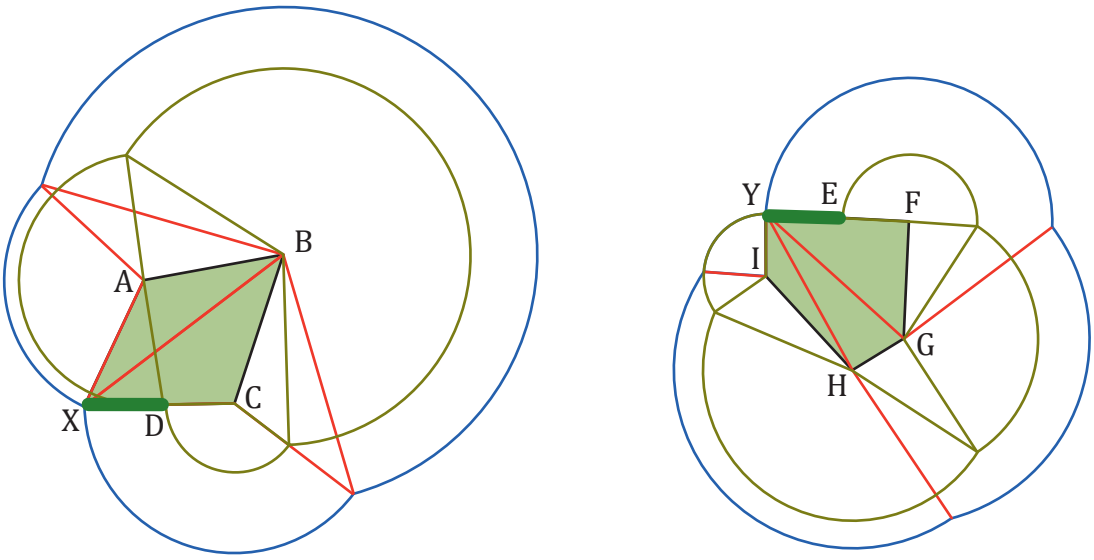


Left: Canopy for the forewing. Right: Canopy for the hindwing.

If these were entirely separate flaps we wouldn't be able to overlap them at all, but because we want them to share a splice line we can bring them closer together. Let's work out exactly how close they can be.

We'll add a splice line to each crown – these are the lines XD and YE on the images below. Consider the point C on the crown of the forewing. How far can this be from point F on the hindwing? The shortest path goes via D (because this is the nearest point to C on the splice line XD) so it makes sense to draw a smaller circle centred at C which passes through D instead of X. We can do this for A and B too, drawing a smaller circle if some point on XD is closer than X (which is the case for A and B too). The union of these three circles is a **subcanopy**, which is entirely contained within the canopy for the whole crown.

Similarly we can draw a subcanopy for the hindwing; for each of F, G, H, and I, if the distance to E is shorter than the distance to Y, we draw a circle passing through E. This is the case for each vertex except I. These circles form a subcanopy for the hindwing.



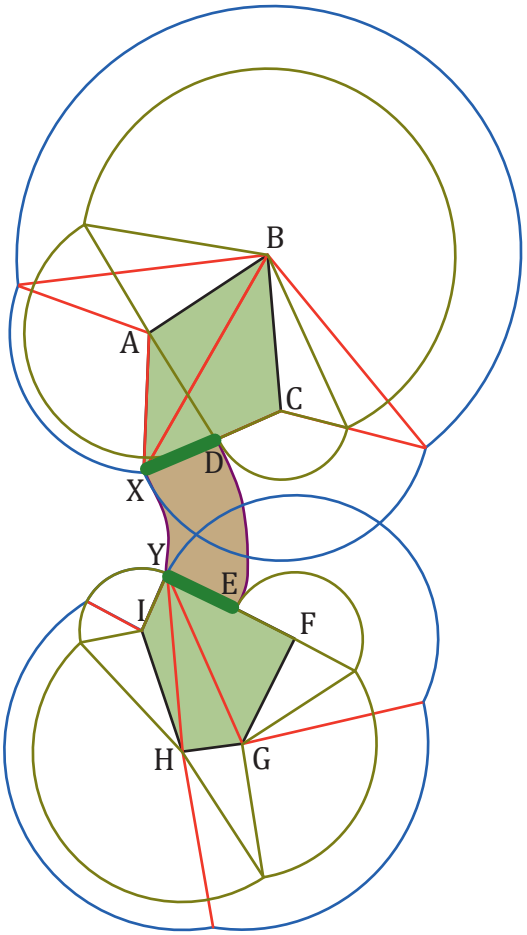
Left: The inner green arcs are the boundary of the subcanopy for the forewing, with splice line XD.
Right: Similarly, the subcanopy for the hindwing, with splice line YE.

Channels

We have to make sure that these two subcanopies don't overlap. But we have an extra condition too: we must be able to fold the two splice lines, XD and YE, onto each other. This second condition is the whole point of this splice line stitching, but how can we guarantee this? This condition can be reformulated to an equivalent but more familiar restriction: we have to be able to draw a continuous region of constant width with one end at XD, and the other end at YE. The width of this region is the same as the lengths XD and YE. I'll call this sort of region a **channel**.

A channel is a special type of river which terminates at a splice line. We are used to a river either terminating at the raw edge of the paper or forming a closed loop. But the example on page 67 shows that a river can terminate at a splice line – this occurred at one end of the river. Other channels might have a splice line at both ends, which is what we want to connect the forewing to the hindwing. This sort of channel is a band that connects the two crowns to form one single canopy. (I like to think of little animals scampering along the pathway to go from one subcanopy to the other, but they need a minimum path width to travel.)

So let's place these subcanopies on the paper and draw a channel between the splice lines (we can place them closer together, but they are deliberately separated to illustrate the channel). Note that the subcanopies mustn't overlap because they show the minimal separation as imposed by the splice line. Whereas we can ignore the original canopies shown in blue because they show the exterior of the whole canopy and are only relevant in relation to other flaps outside the canopy. In fact, the more overlap between the original canopies the better, because this area of overlap shows the amount of paper saved by using the splice line instead of splice points.



Two subcanopies which mustn't overlap, connected by a channel. The boundary of the whole shape – the union of the original canopies (blue) together with the channel – is one large canopy for the whole forewing/hindwing flap.

The arrangement (at last)

We've gotten ahead of ourselves though – we need to be flexible about the shape of the channel because we don't actually know where either of subcanopies will go on the paper. When it comes to finalising an arrangement, the objects we need to arrange are:

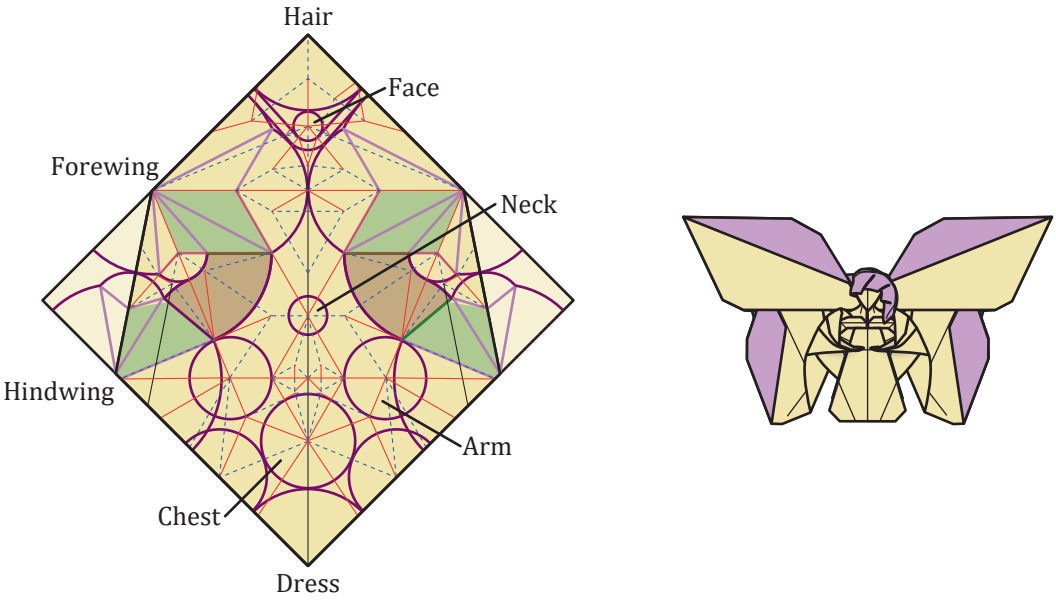
- Circles – one per leaf flap
- Rivers – one per branch edge
- Canopies – one per crown which is not connected to another crown via a splice line
- Subcanopies – one per crown which is connected to another crown via a splice line
- Channels – one per splice line which connects two crowns

Arranging these objects is much the same as for tree theory, but with more awkward shapes. As mentioned before, we haven't shown that merely arranging these objects so that they don't overlap guarantees foldability. But it's a very good starting point.

Below you can see the final crease pattern for Psyche. The hindwings are a slightly simplified shape to fit better within the square and the paper at the raw corner isn't wasted but rather used for a colour change. One thing of note is the overlap between the canopy for the hindwing and the circle for the arm. The consequence of this is that the arm and hindwing are closer together than expected. This seems to break the rules of the theory, but this is really just a matter of how we frame it; these overlaps can always be 'removed' by adding one or more rivers in the right place, without changing the way we fold the paper.

In the past, I've always made this edit 'in hindsight', but I've decided to keep it in here as it reflects the true way I designed the model. It's also a reminder that what looks like breaking a rule often isn't actually a problem, it just does something different from the rule's aim. We shouldn't limit ourselves to existing rules, but keep exploring to make our own origami designs in our own unique ways.

On that note, I really hope you enjoy using canopy theory and that it allows you to expand the sorts of designs you can make. But more importantly don't stop there – keep adding new creative ways to expand this theory.



Left: Crease pattern for Psyche, with crowns (green) and channels (brown). Right: Final model.

Note

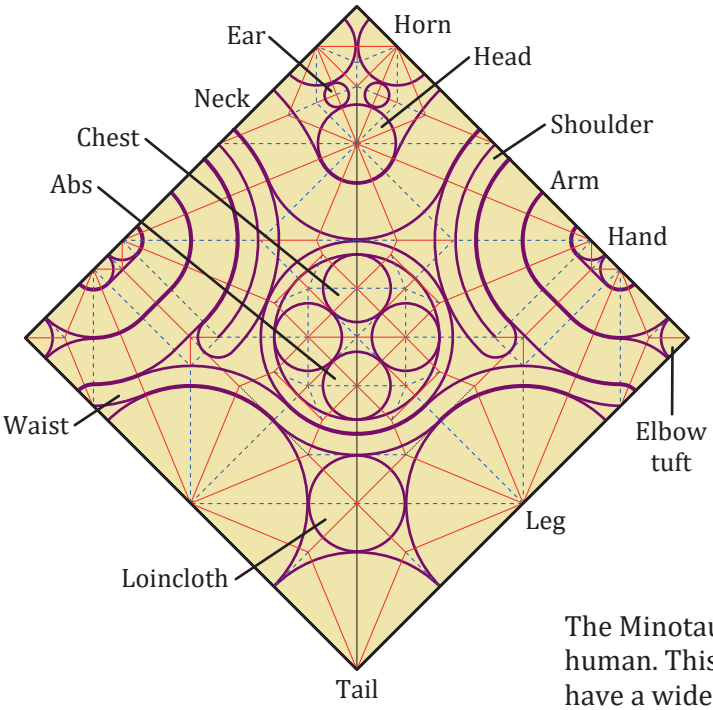
After reading this chapter, some people may think that I've spent far too much time pondering theories for how to fold paper. Those people are clearly correct.

Minotaur

First time: 50cm/20''

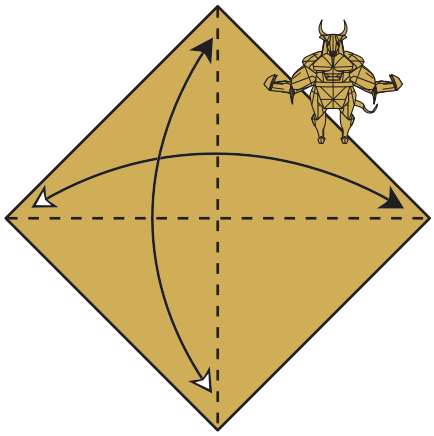
Paper preferences:
- Thin
- Shapeable
- Textured
- Tearproof

Recommended papers:
- Foil-backed paper
- Sandwich paper
- Double tissue

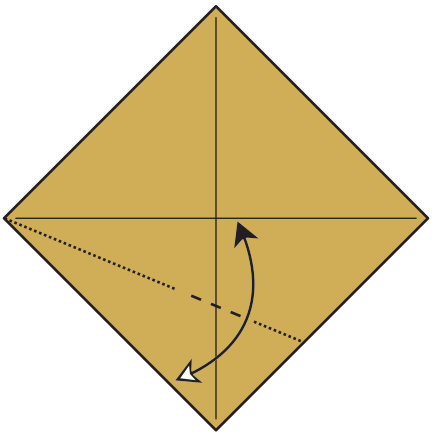


The Minotaur is a monstrous hybrid between a bull and a human. This model uses only one side of the square, so you have a wide choice of suitable papers. The best choices will allow the paper to hold its shape well, such as papers with a layer of foil.

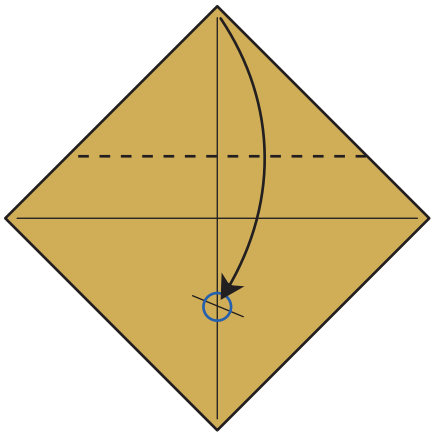
Start body colour side up.



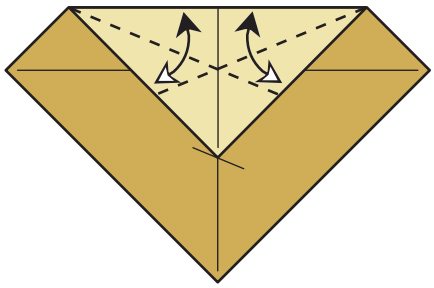
1. Fold and unfold the diagonals.



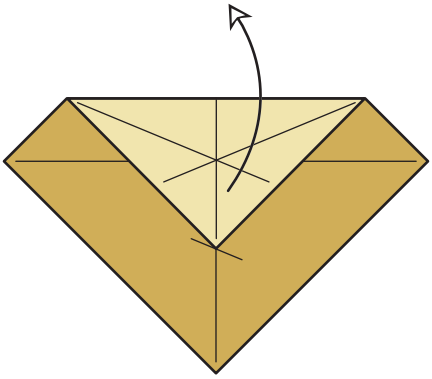
2. Fold the bottom-left raw edge to the horizontal crease and unfold. Only mark the paper firmly where the fold-line crosses the vertical crease.



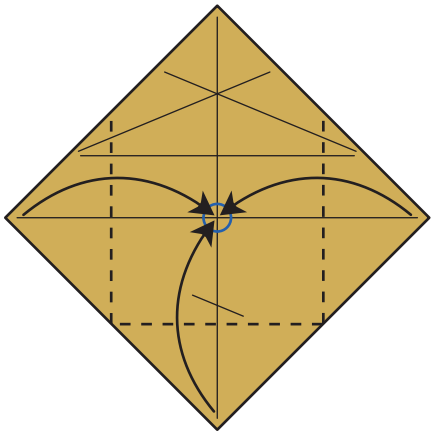
3. Fold the top corner to the circled point.



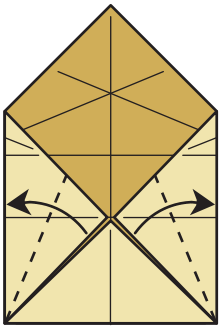
4. Fold and unfold two angle bisectors.



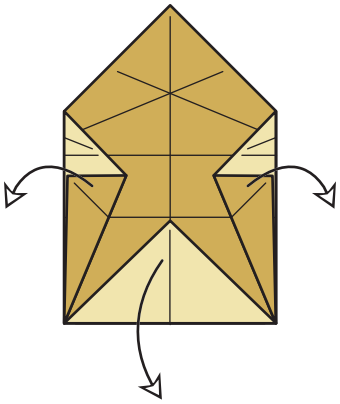
5. Unfold step 3.



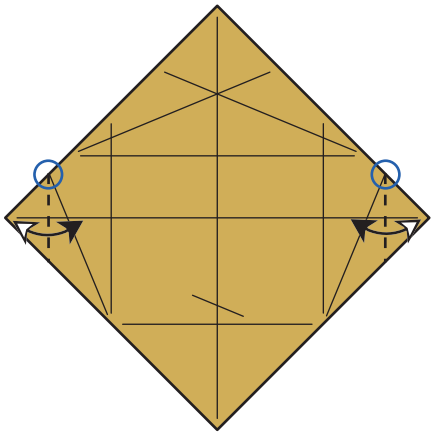
6. Fold three raw corners to the centre.



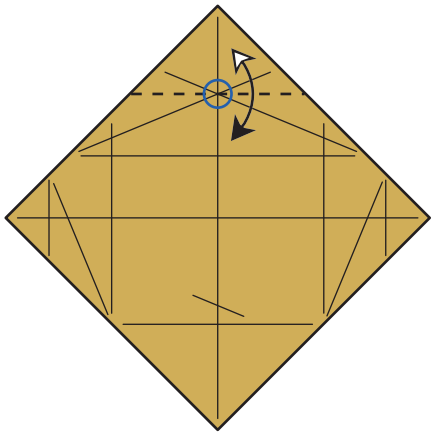
7. Fold the raw edges to the folded edges.



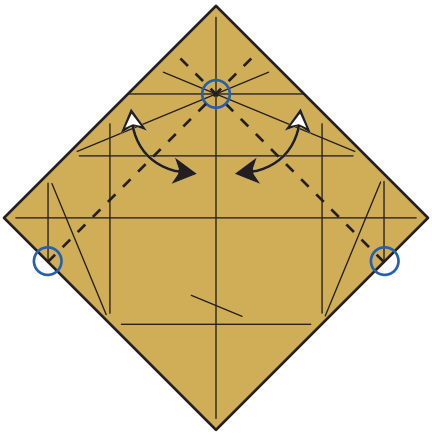
8. Unfold steps 6 and 7.



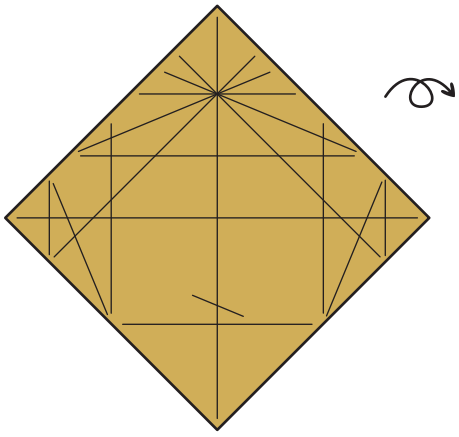
9. Fold the raw corners in using vertical fold-lines which go through the circled points, then unfold.



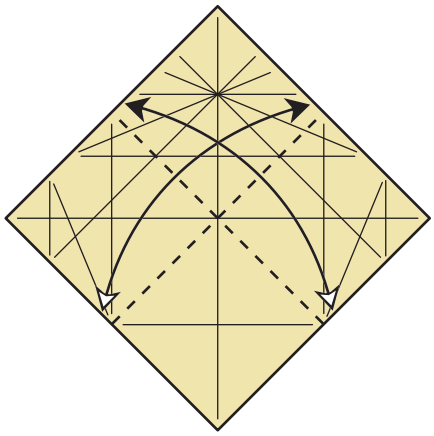
10. Fold and unfold a horizontal line through the circled point.



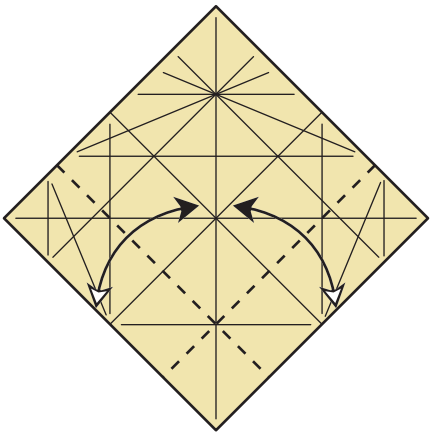
11. Fold and unfold through the circled points.



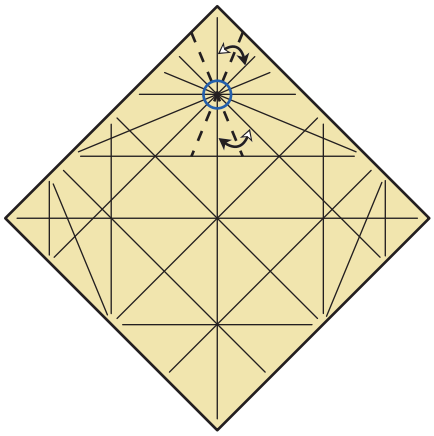
12. Turn the paper over.



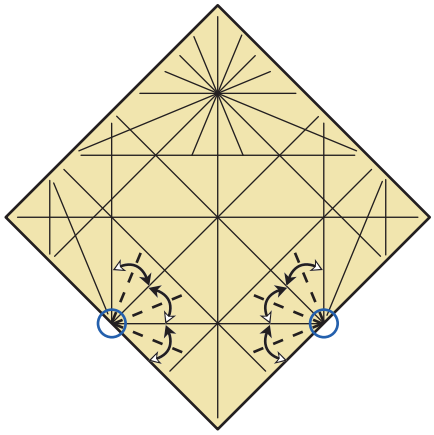
13. Fold and unfold opposite raw edges together.



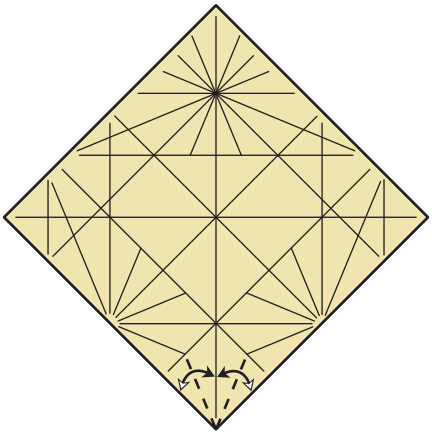
14. Fold and unfold to the creases you just made.



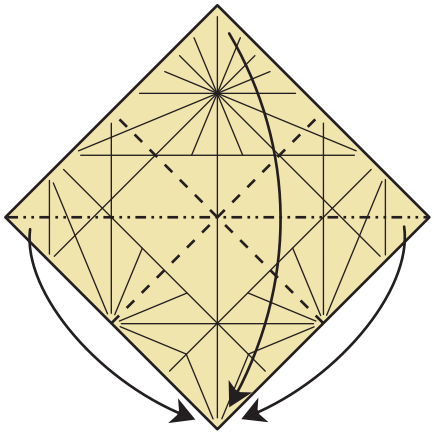
15. Fold and unfold two angle bisectors.



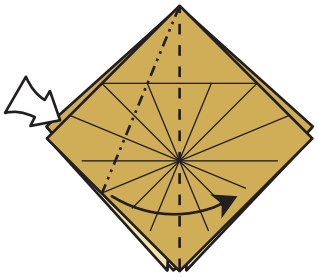
16. Fold and unfold six angle bisectors.



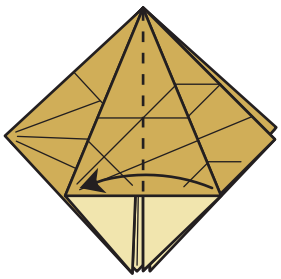
17. Fold and unfold two angle bisectors.



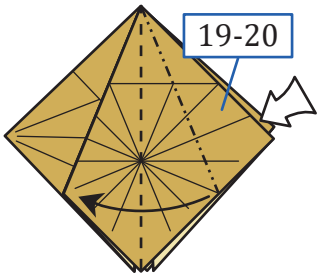
18. Preliminary-fold.



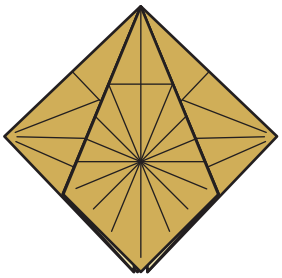
19. Squash-fold the edge.



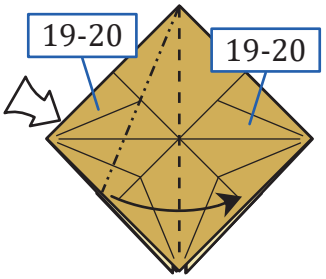
20. Fold the edge back to the left.



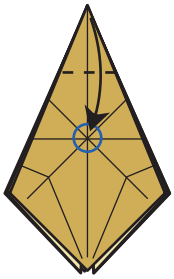
21. Repeat steps 19 and 20 on the right.



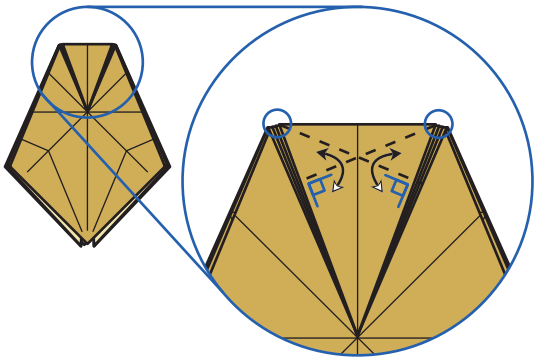
22. Turn the paper over.



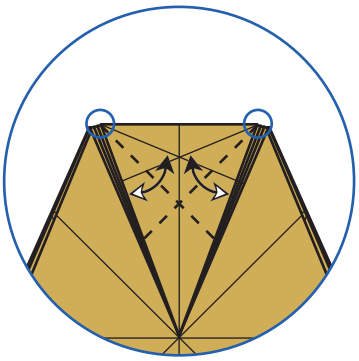
23. Repeat steps 19 and 20 on the left and right.



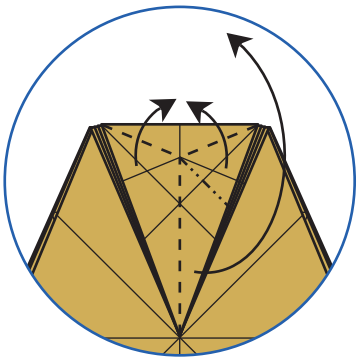
24. Fold the top corner to the circled point. Be as accurate as you can, and crease firmly through all layers.



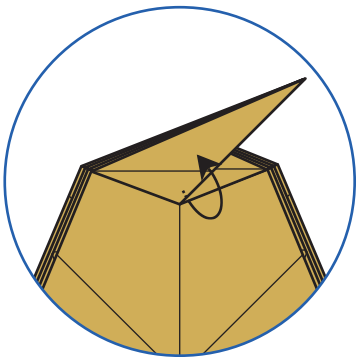
25. Fold and unfold the thick edges onto themselves.



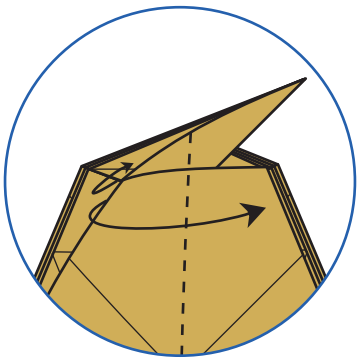
26. Fold and unfold two angle bisectors.



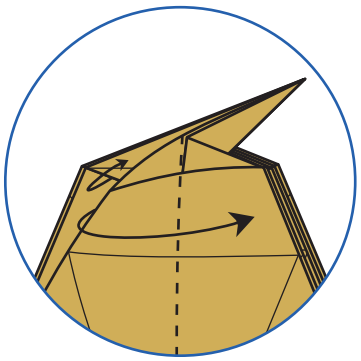
27. Rabbit-ear the thick corner up and to the right.



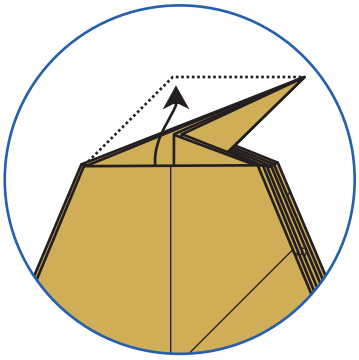
28. Wrap one layer to the front. You may prefer to fold the flap up and then closed-sink it down behind the nearest layer.



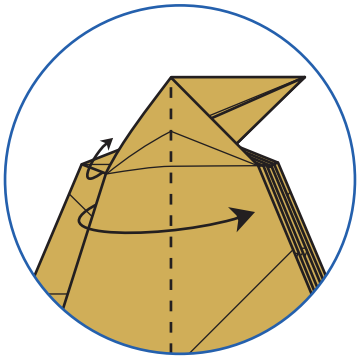
29. Carefully fold one edge to the right, releasing a trapped edge.



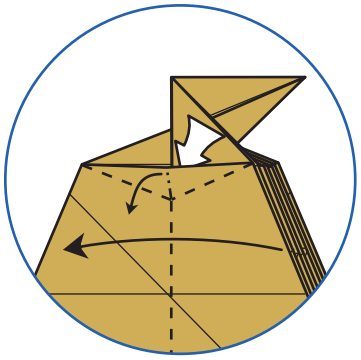
30. Carefully fold another edge to the right, releasing a trapped edge.



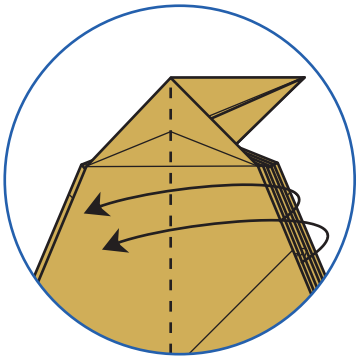
31. Unsink to pull some paper up. You may need to unfold some of the paper to do this.



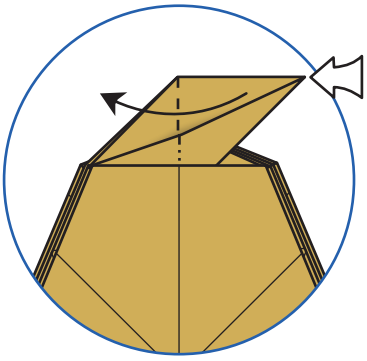
32. Fold one final edge to the right, releasing a trapped edge.



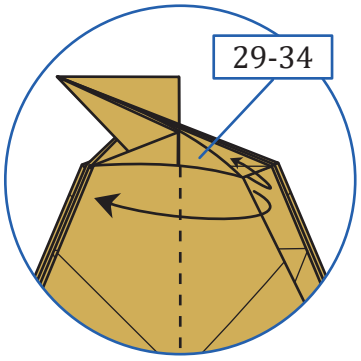
33. Fold one flap back to the left, folding the horizontal edge down, as shown.



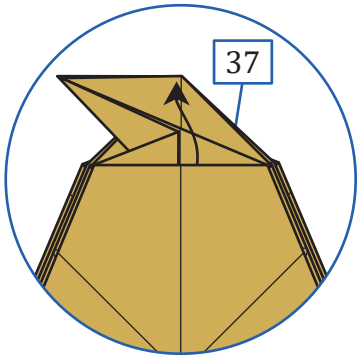
34. Fold two edges to the left.



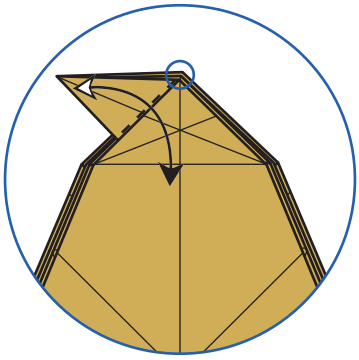
35. Reverse-fold the point to the left.



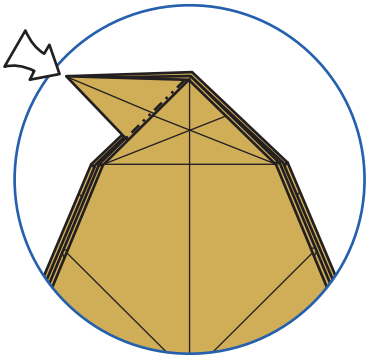
36. Repeat steps 29 to 34 on the right.



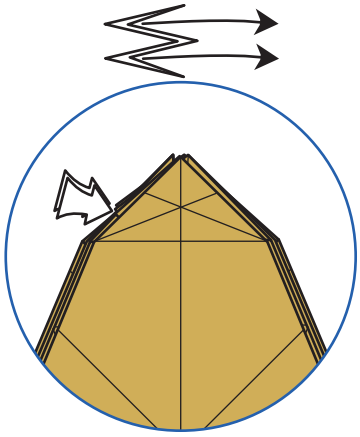
37. Unsink to pull some paper up. You may need to unfold some of the paper to do this. Repeat behind.



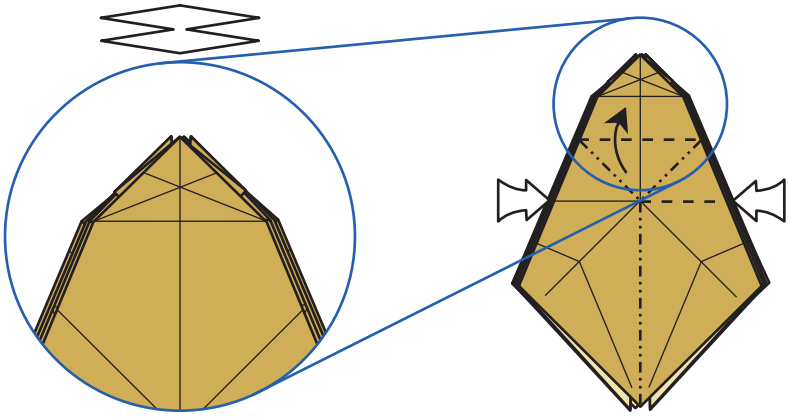
38. Fold firmly through all layers of the flap, then unfold. Make sure the fold-lines go neatly through all four corners at the top.



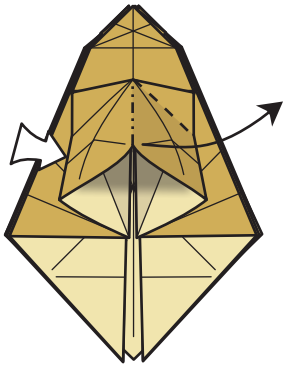
39. Open-sink using the creases you just made. You will need to open up the paper to achieve this.



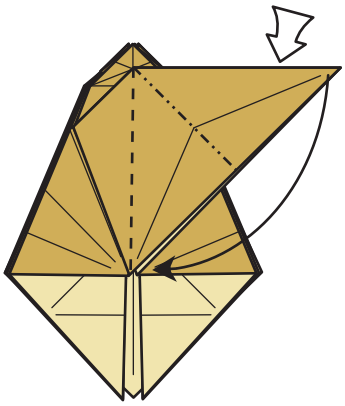
40. Reverse-fold and rearrange the square you just sank into a small preliminary base.



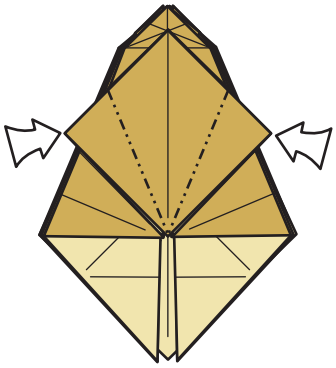
41. Bring the central point upwards, squeeze the sides in, and begin to collapse using existing creases.



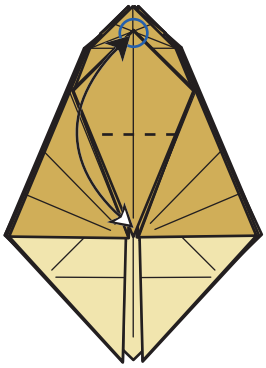
42. Flatten the corner to the right.



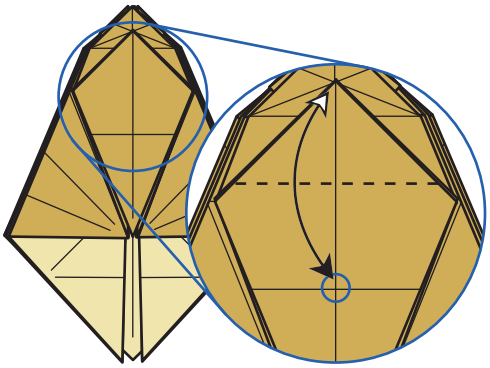
43. Squash-fold the corner.



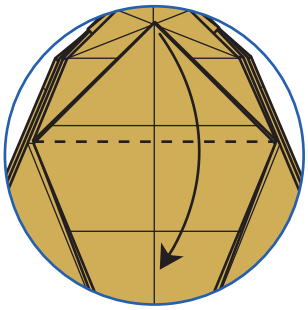
44. Reverse-fold using existing creases.



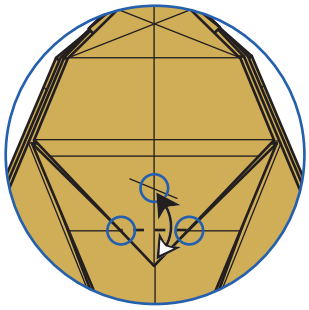
45. Fold the raw corner to the circled point, then unfold.



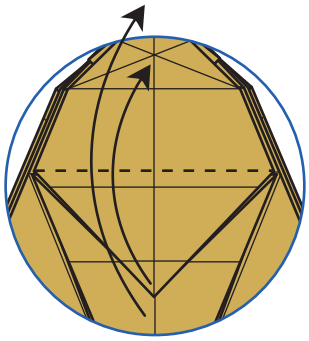
46. Fold the corner to the circled point, then unfold.



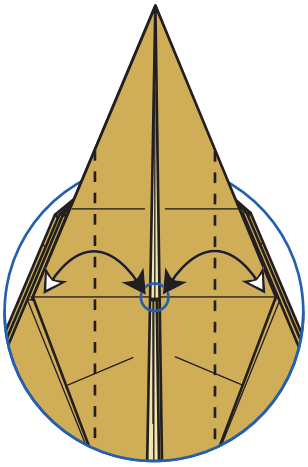
47. Fold the flap down.



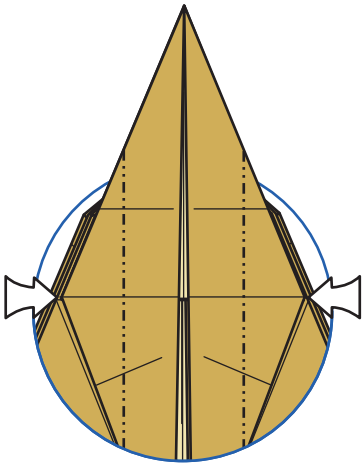
48. Fold and unfold.



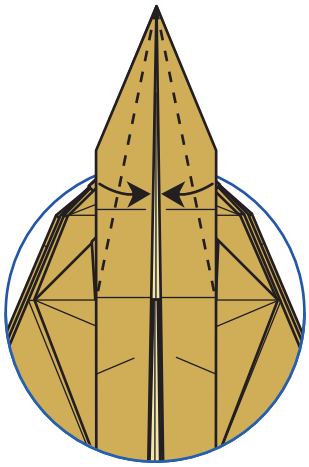
49. Fold two flaps up.



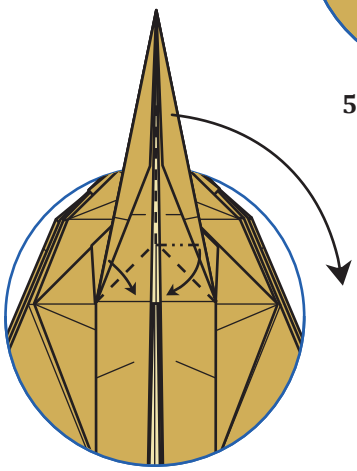
50. Fold and unfold.



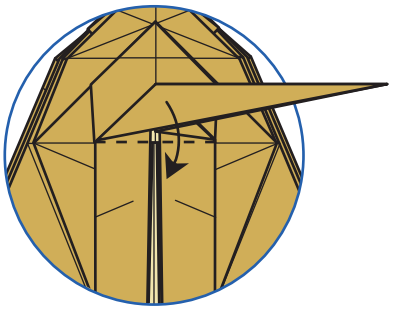
51. Open-sink.



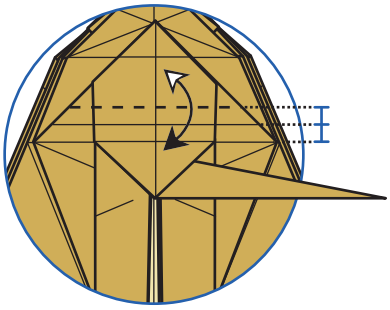
52. Fold the edges in.



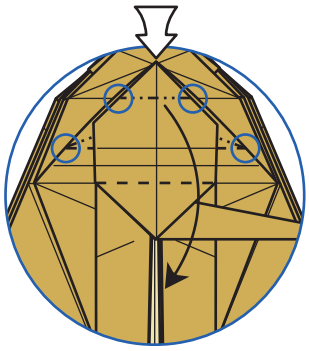
53. Rabbit-ear the flap so that the vertical valley fold becomes horizontal.



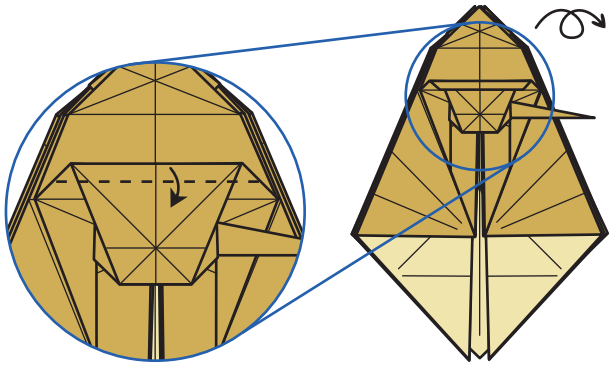
54. Fold the flap down.



55. Fold and unfold so that the distances shown are equal.

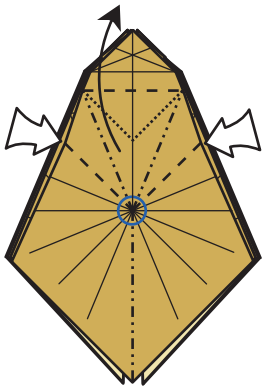


56. Spread-sink the corner, making new mountain folds between the circled points.

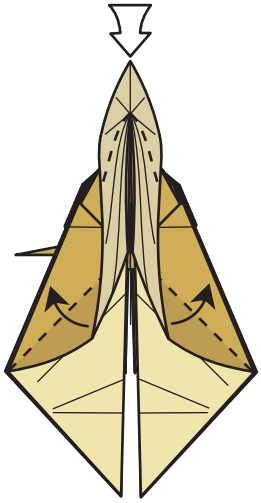


57. Fold the edge down.

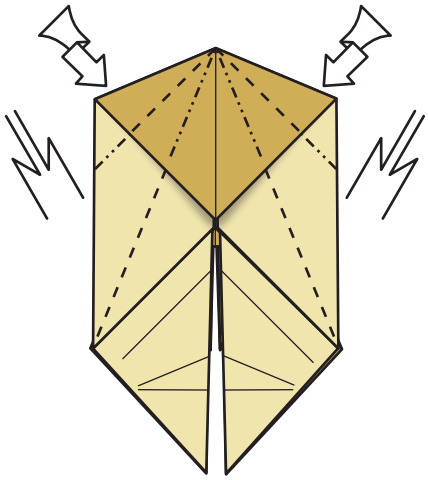
58. Turn the paper over.



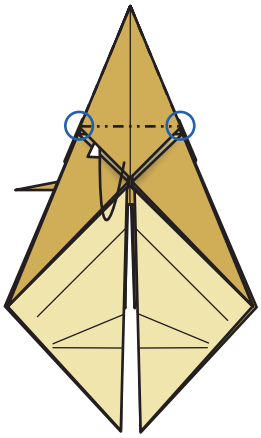
59. Bring the circled point upwards and squeeze the sides in.



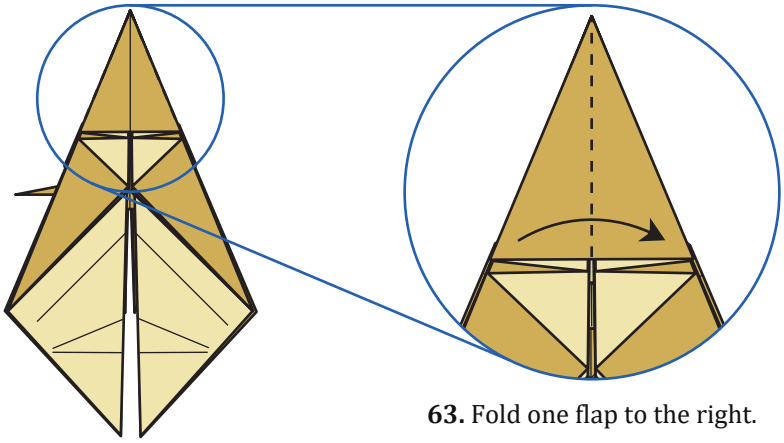
60. Squash-fold the raw corner so the paper lies flat.



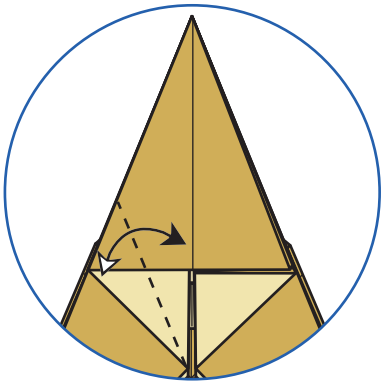
61. Crimp the edges in and out using existing creases.



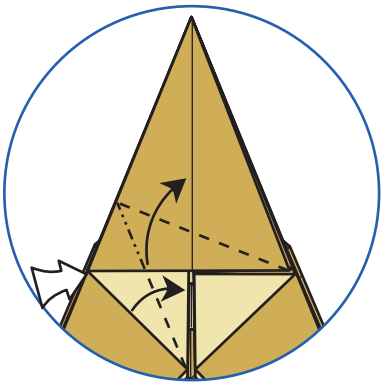
62. Mountain-fold the raw corner underneath.



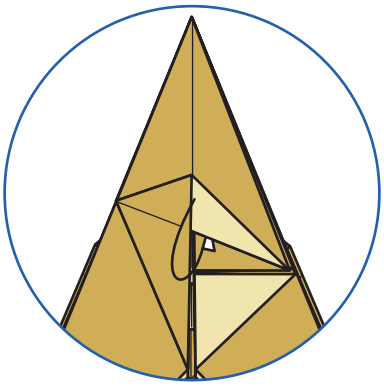
63. Fold one flap to the right.



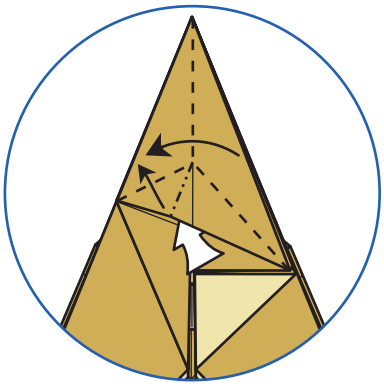
64. Fold an angle bisector and unfold.



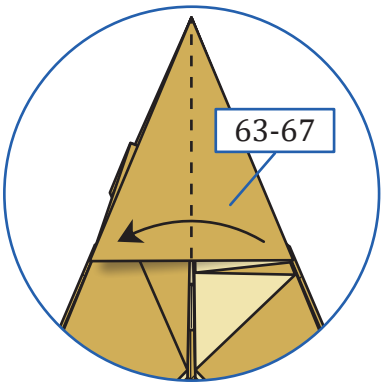
65. Swivel-fold.



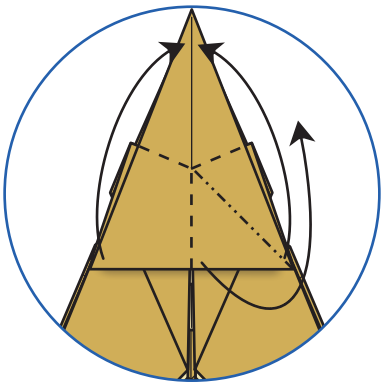
66. Tuck the flap underneath.



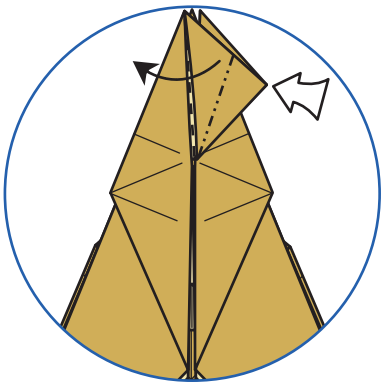
67. Fold the flap to the left, while bringing the folded edge upwards.



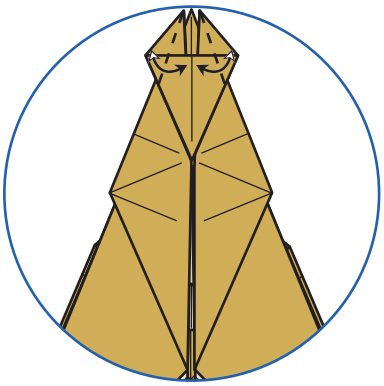
68. Repeat steps 63 to 67 on the right.



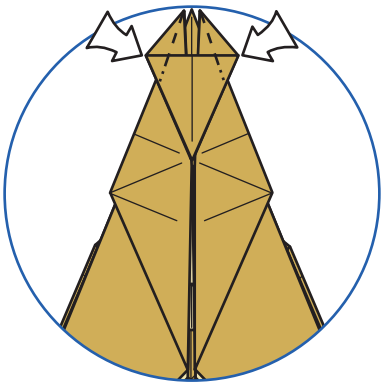
69. Fold the two corners to the top and swing the excess paper to the right.



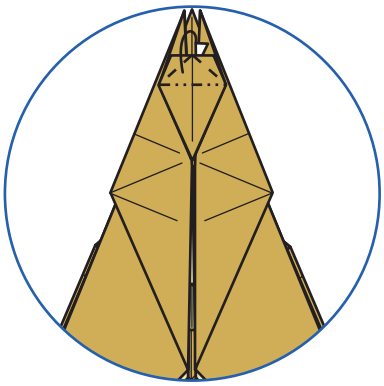
70. Squash-fold.



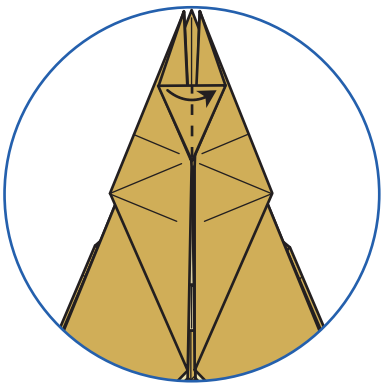
71. Fold along angle bisectors and unfold.



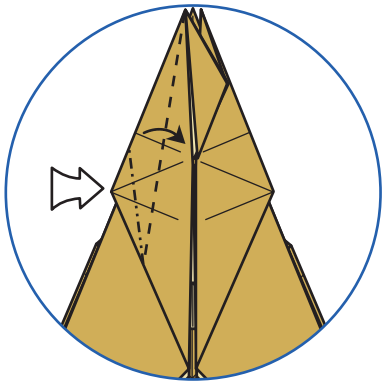
72. Reverse-fold using the creases you just made.



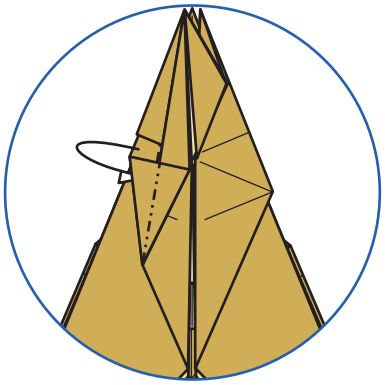
73. Mountain-fold the edge behind.



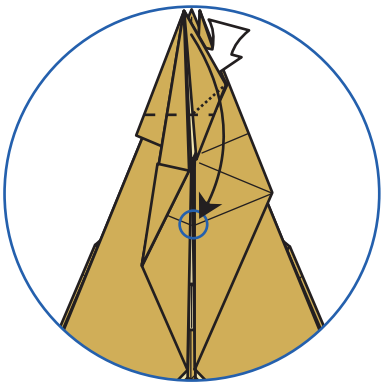
74. Fold one edge to the right.



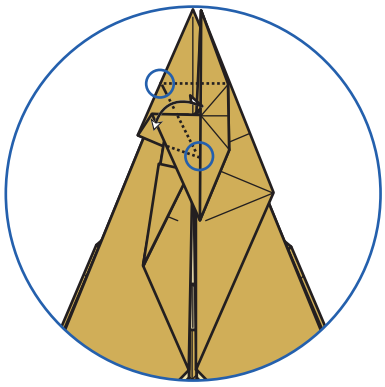
75. Spread-sink the corner by folding along a thin angle bisector.



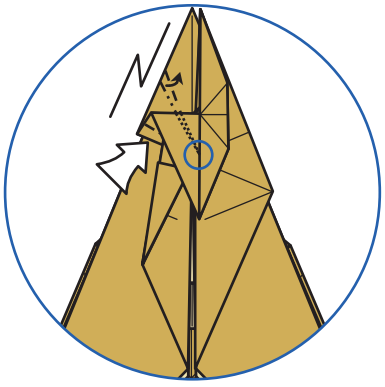
76. Mountain-fold the edge behind.



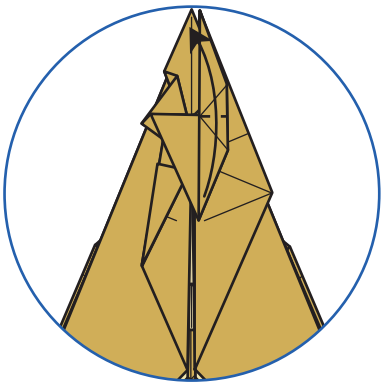
77. Pull the near corner down as far as it will go without moving the corner on the right.



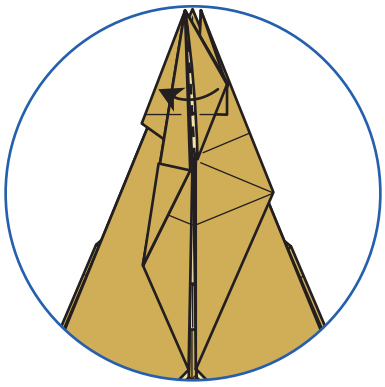
78. Pinch a mountain fold between the circled points. You may find it easiest to combine this with step 79 at the same time.



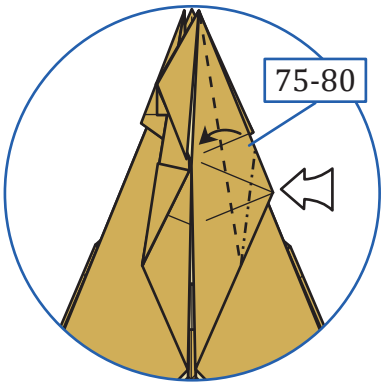
79. Crimp using the mountain fold you just made, pivoting about the circled point.



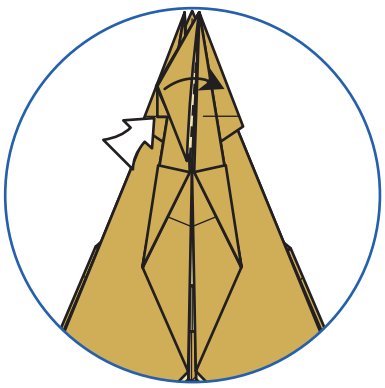
80. Fold the corner up.



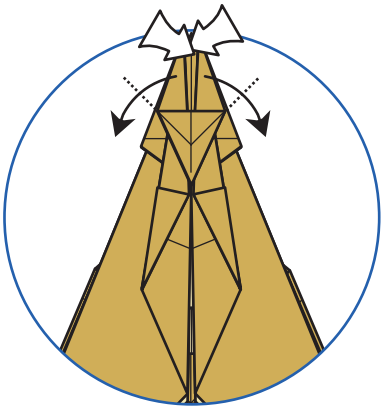
81. Fold the connected flaps to the left.



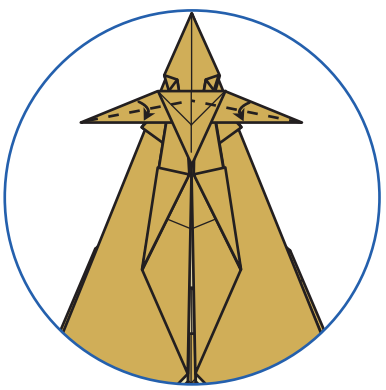
82. Repeat steps 75 to 80 on the right.



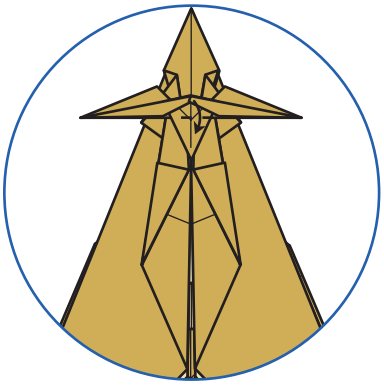
83. Fold one edge to the right, flattening the corner shown.



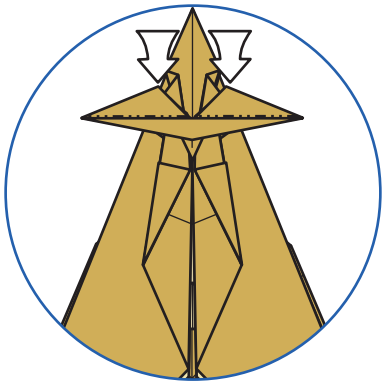
84. Reverse-fold the corners to the sides.



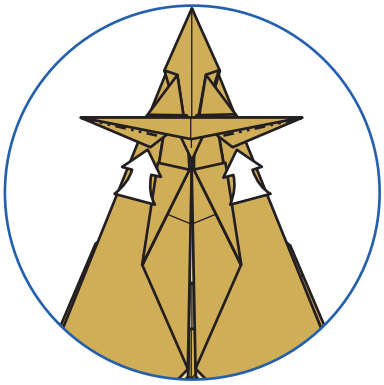
85. Fold a narrow rabbit-ear.



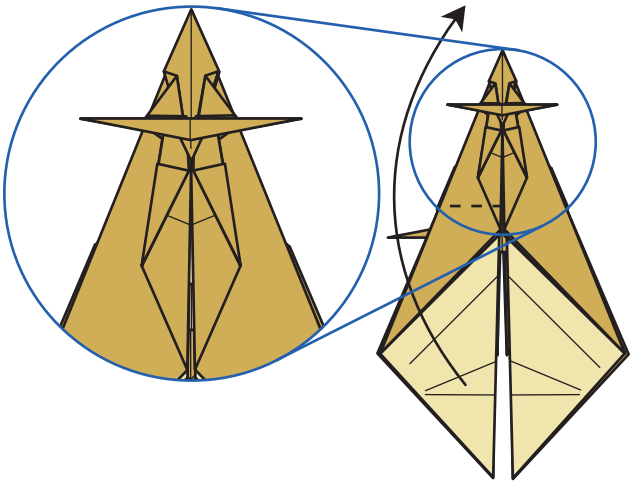
86. Fold the narrow flap down.



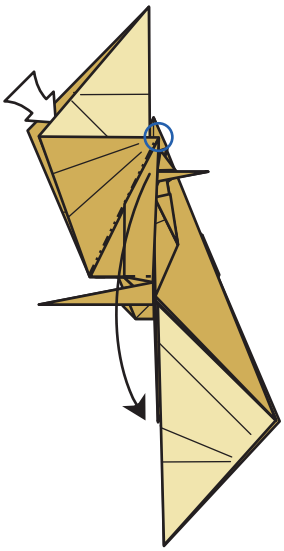
87. Reverse-fold.



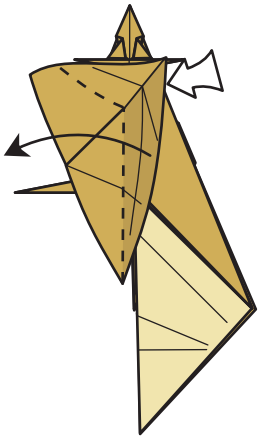
88. Reverse-fold.



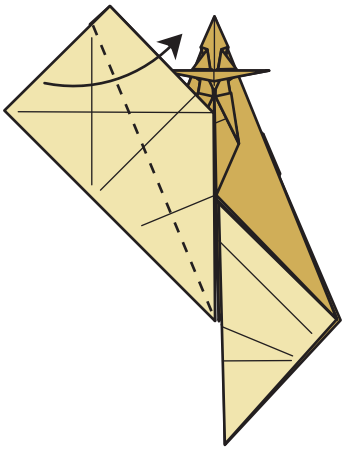
89. Fold the large flap on the left up.



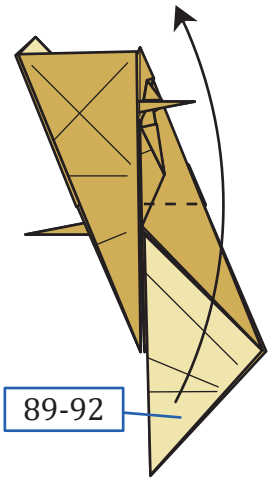
90. Bring the circled corner down and fold along the existing mountain fold-line, as shown. The paper won't lie flat until after step 91.



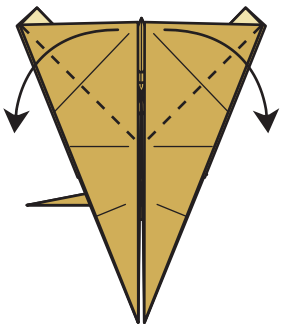
91. Flatten the corner to the left along existing creases.



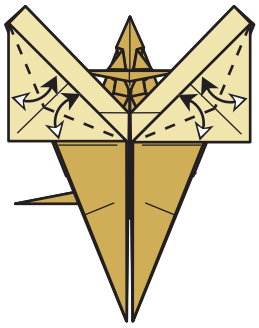
92. Fold the edge to the right.



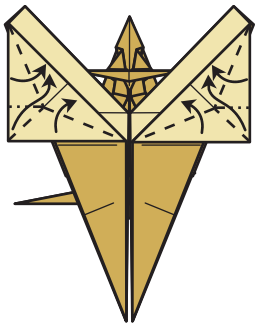
93. Repeat steps 89 to 92 on the right.



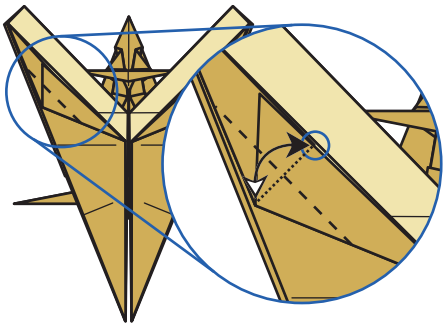
94. Fold the raw corners down using existing creases.



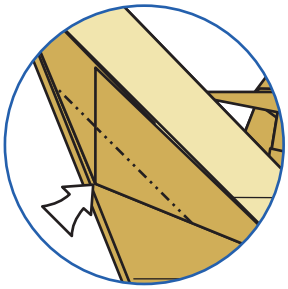
95. Fold and unfold four angle bisectors.



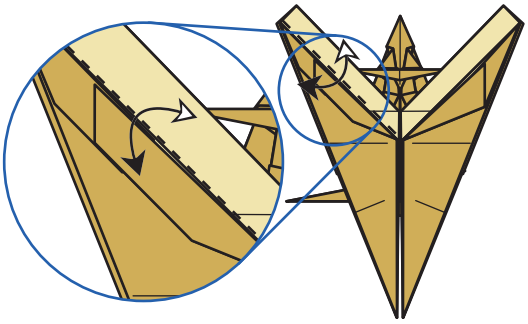
96. Rabbit-ear the raw corners.



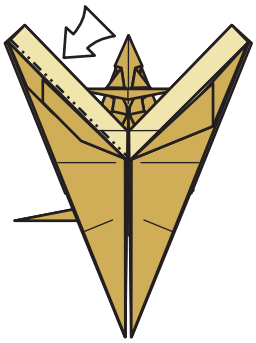
97. Fold and unfold.



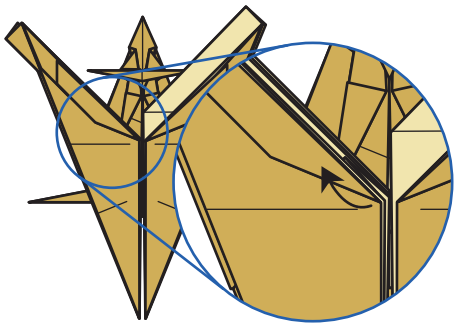
98. Open-sink.



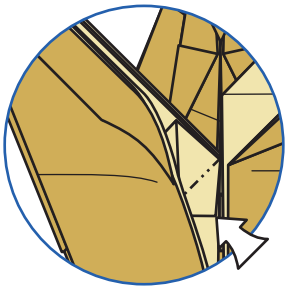
99. Fold and unfold along the edge of the white region.



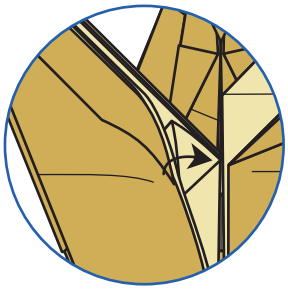
100. Open-sink.



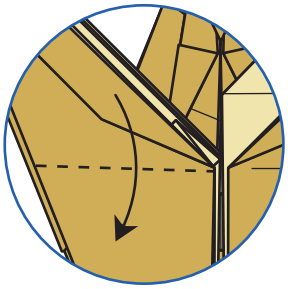
101. Lift two edges slightly so that the layers underneath are visible.



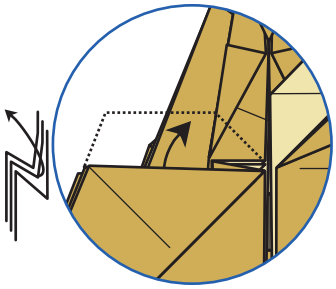
102. Reverse-fold all five edges together.



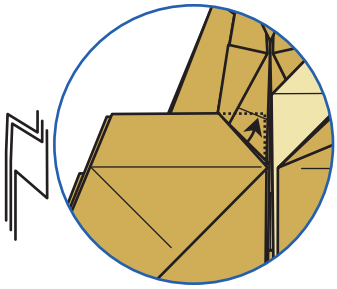
103. Fold the layers back down.



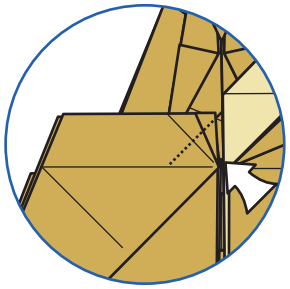
104. Fold the flap down along an existing horizontal crease.



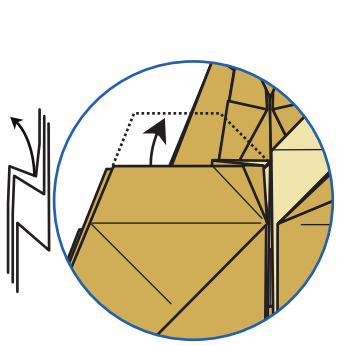
105. Move two folded edges on the left upwards by unsinking the paper so the hidden valley becomes a mountain.



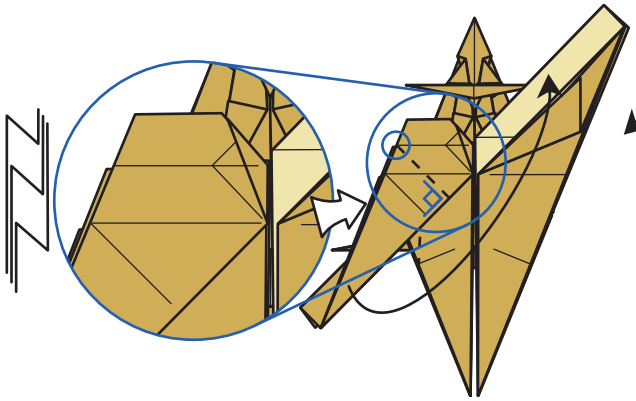
106. Reverse-fold the edges. You may have done this as part of step 105 already.



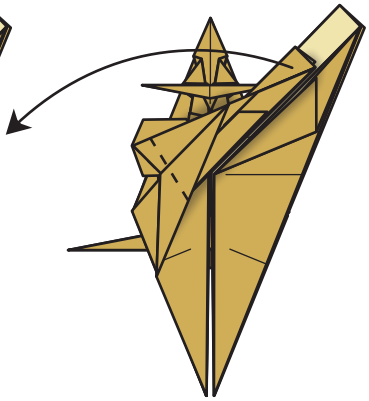
107. Reverse-fold all three edges together. This is much like step 102, but here there is an edge which cannot be reversed.



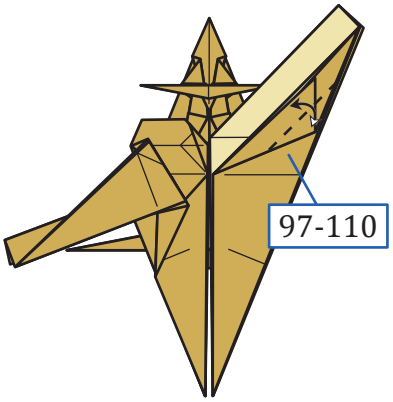
108. Unsink one layer on the left upwards.



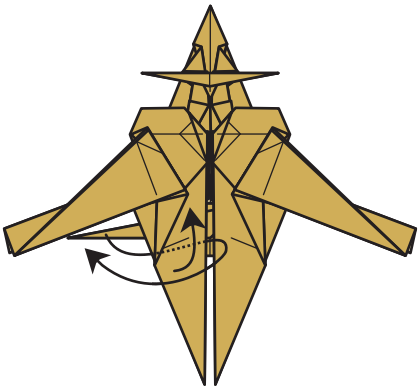
109. Swivel-fold the paper up and to the right using a fold-line which goes through the circled point.



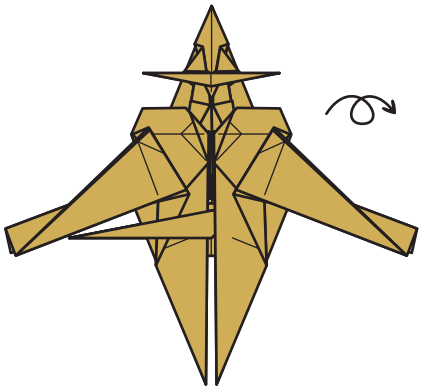
110. Fold the paper to the left so it is slightly higher than it was before step 109.



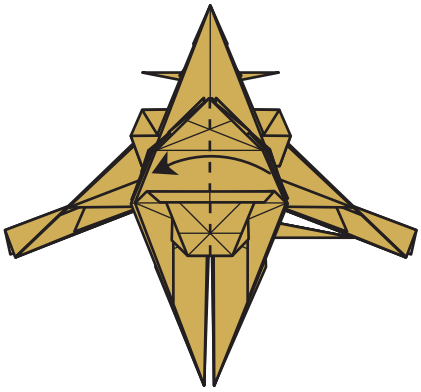
111. Repeat steps 97 to 110 on the right arm.



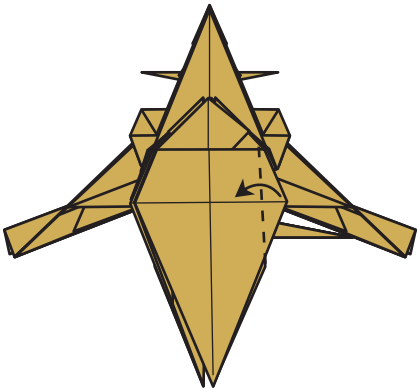
112. Bring the tail point to the front.



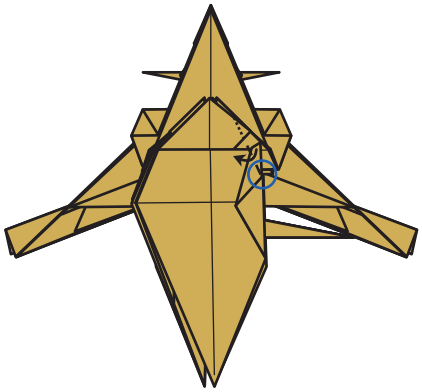
113. Turn the paper over.



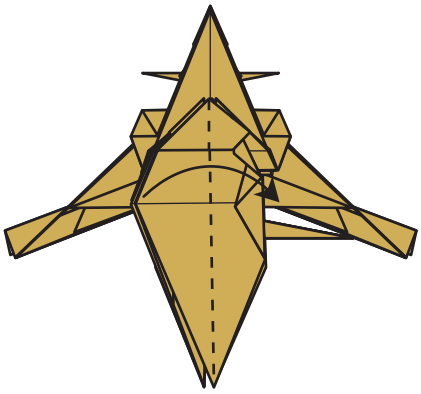
114. Fold one flap to the left.



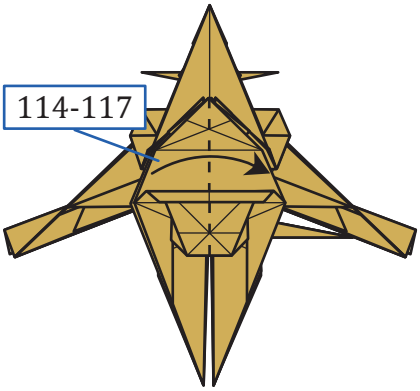
115. Fold the edge over along a fold-line which is directly above a folded edge on the layer below.



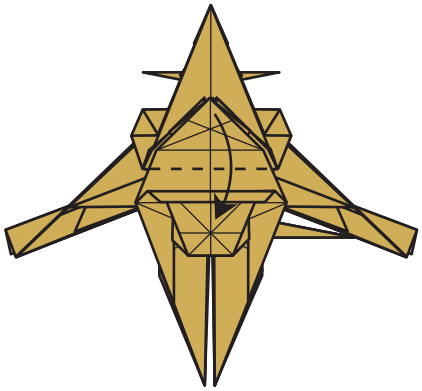
116. Fold the corner over as far as it will go.



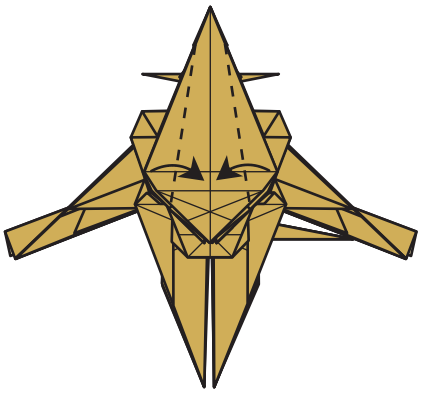
117. Fold one flap to the right.



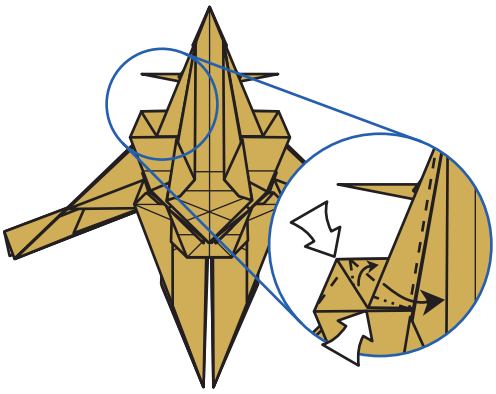
118. Repeat steps 114 to 117 on the left.



119. Fold the connected flaps down.

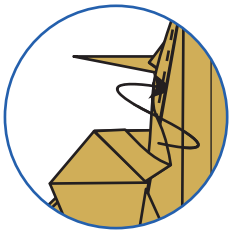


120. Fold two edges in so that they end up vertical. Fold them as far as they will go.

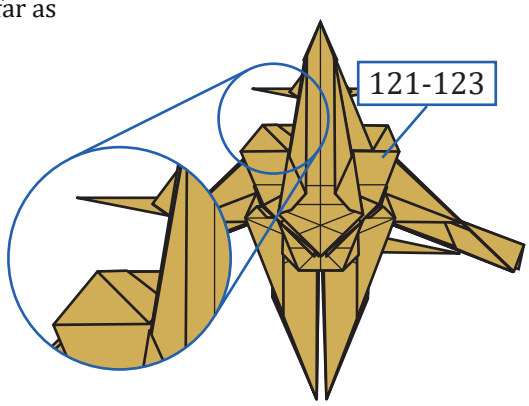


121. Swivel-fold on each side.

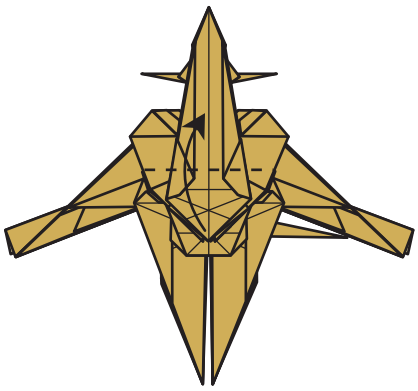
122. Carefully wrap the edge behind.



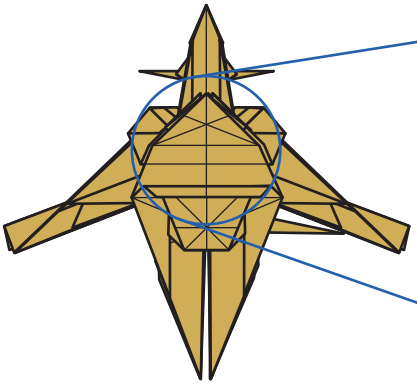
123. Tuck the edge underneath.

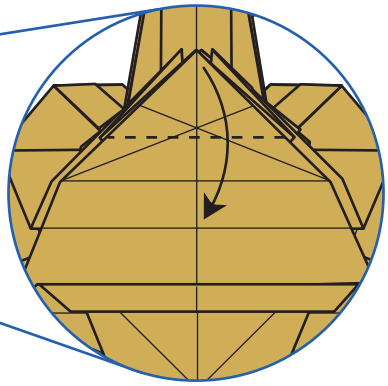


124. Repeat steps 121 to 123 on the right shoulder.

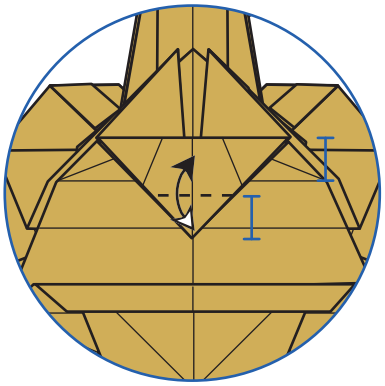


125. Fold the connected flaps up.

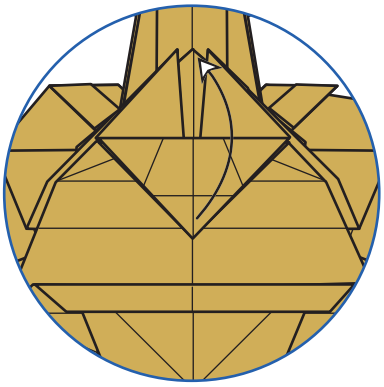




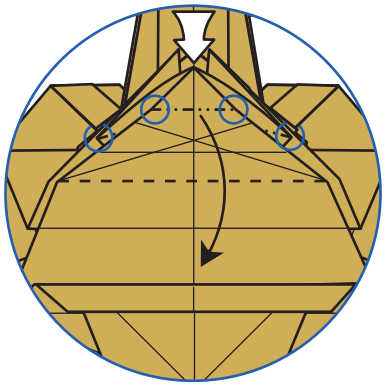
126. Fold the near flap down as far as it will go without stretching the edges at the sides.



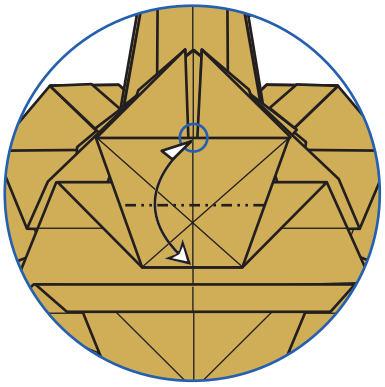
127. Fold and unfold so that the indicated distances are the same.



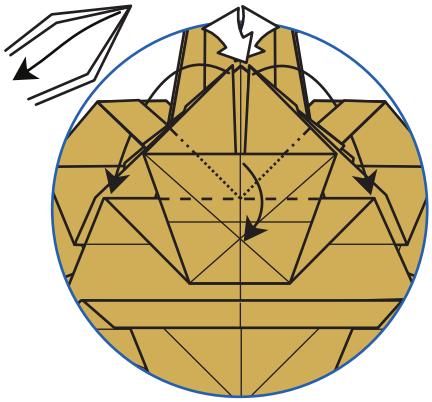
128. Unfold step 126.



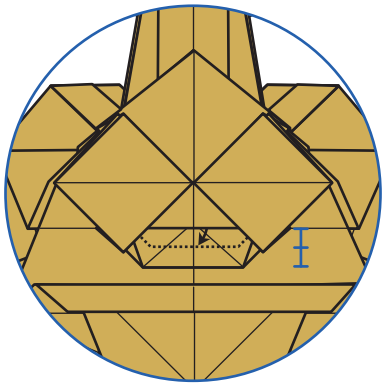
129. Spread-sink the corner, by using creases made in step 126 and 127, and making new mountain folds between the circled points.



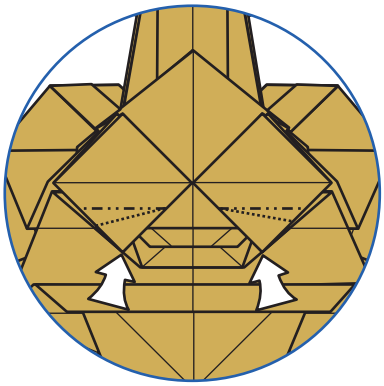
130. Fold and unfold as a **mountain fold**.



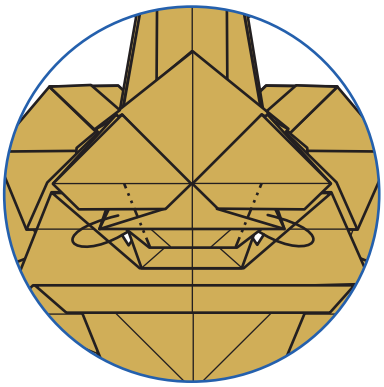
131. Fold the near edge down using an existing horizontal crease and squash-fold two corners sideways.



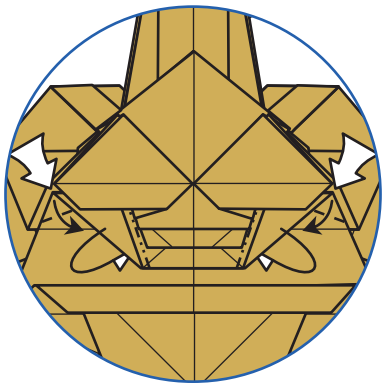
132. Carefully pull the central section of the mountain fold made in step 130 down. You will need to form small gussets at the sides of the crease to flatten the paper.



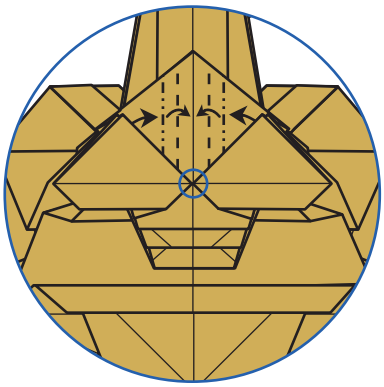
133. Reverse-fold the corners inside.



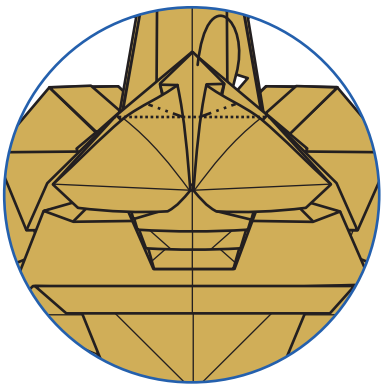
134. Mountain-fold the corners behind.



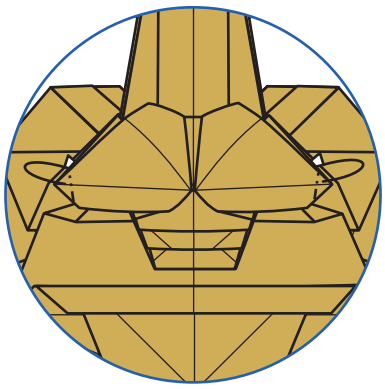
135. Swivel-fold the edges underneath on each side.



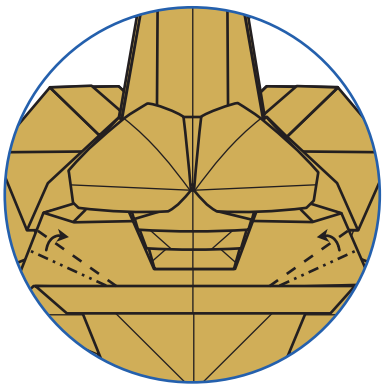
136. Pull the circled point forwards, and pleat the layers behind. The paper won't lie flat from now on.



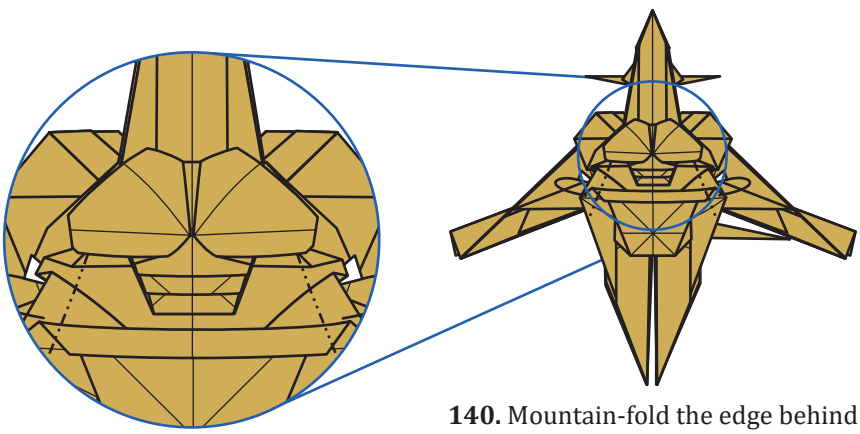
137. Fold the corner behind, folding the nearer layers at an angle.



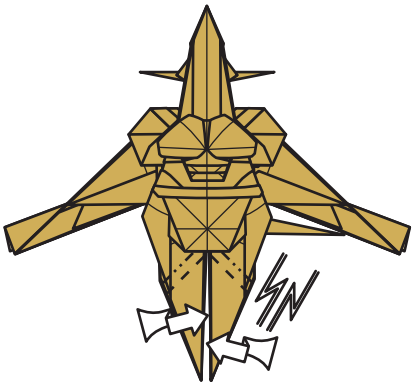
138. Mountain-fold the corners behind.



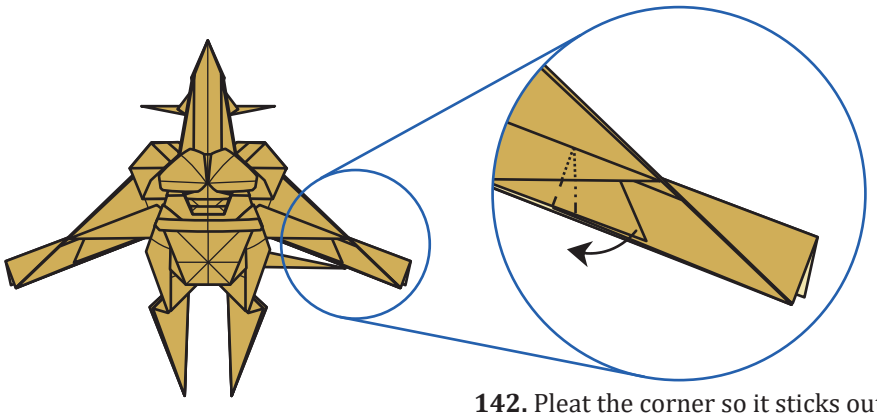
139. Pleat the sides up slightly.



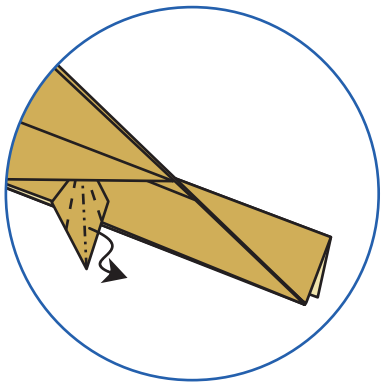
140. Mountain-fold the edge behind to narrow the waist.



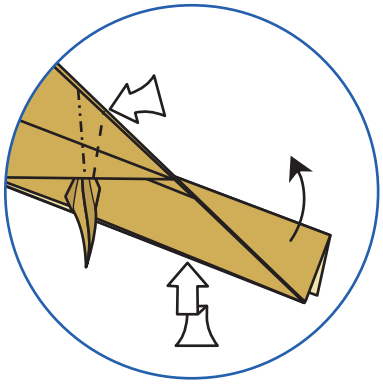
141. Reverse-fold the legs in and out.



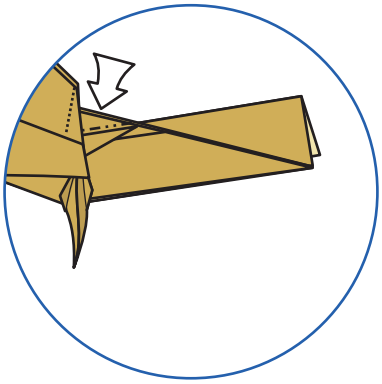
142. Pleat the corner so it sticks out pointing downwards.



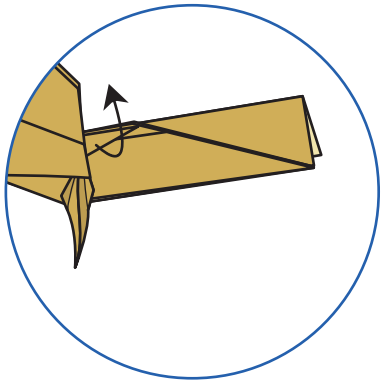
143. Pleat the corner and bend it to look like a tuft of hair.



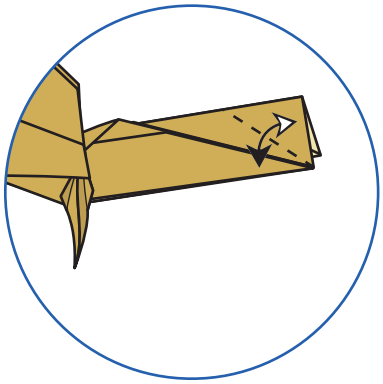
144. Crimp the flap upwards.



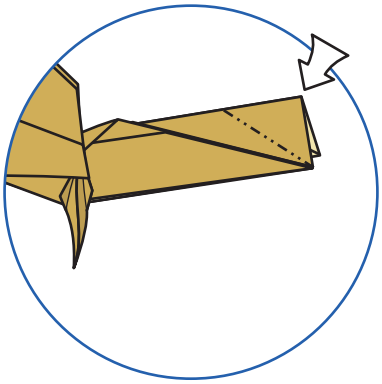
145. Sink the edge down slightly.



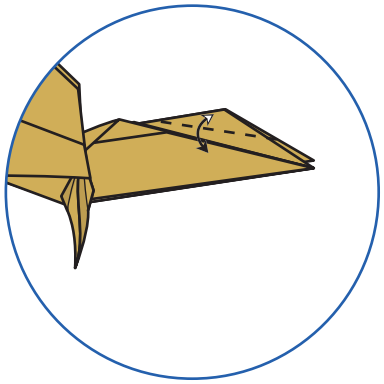
146. Pull the edge up a little.



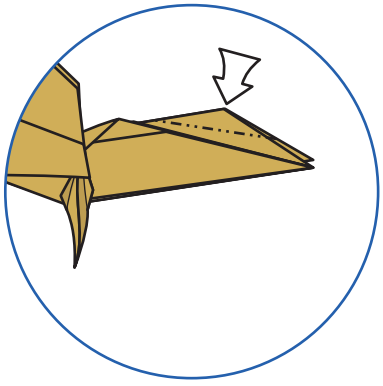
147. Fold and unfold.



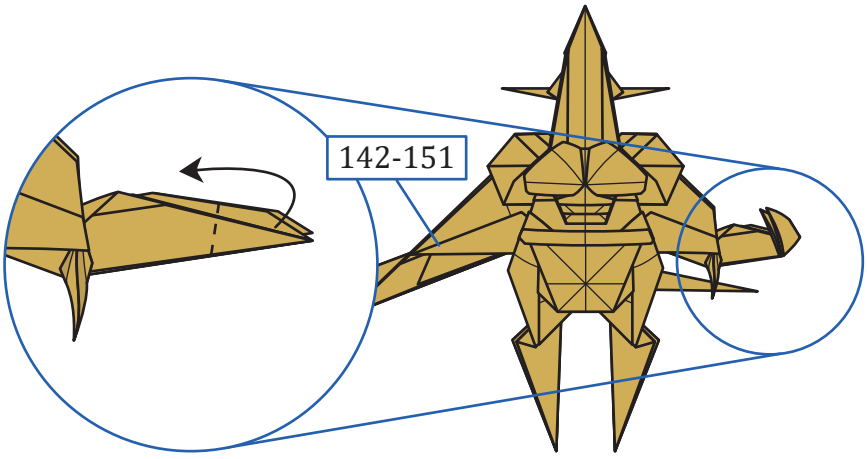
148. Reverse-fold the edge down.



149. Fold and unfold.

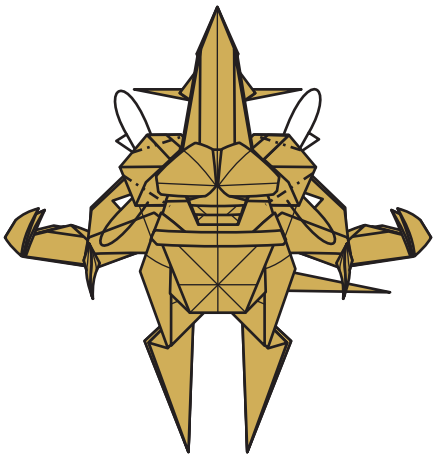


150. Open-sink.

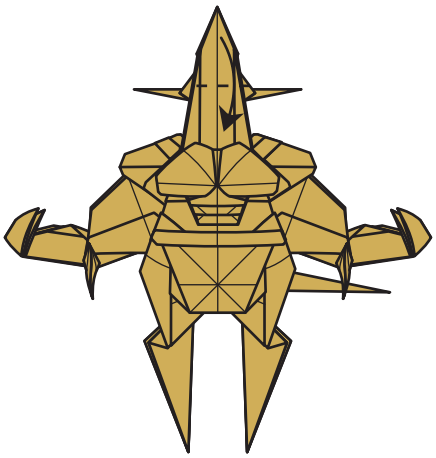


151. Fold the points up.

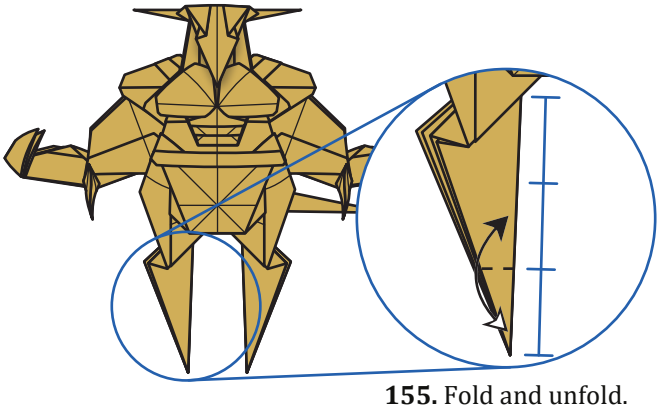
152. Repeat steps 142 to 151 on the left arm.



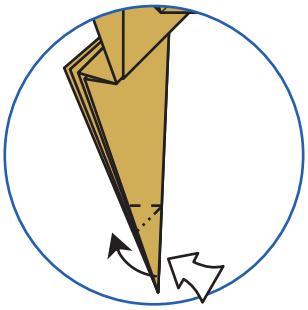
153. Mountain-fold four corners around the shoulders.



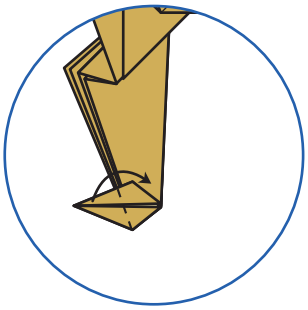
154. Fold the head down using a fold-line which is level with the tops of the horns.



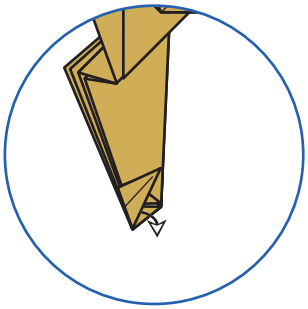
155. Fold and unfold.



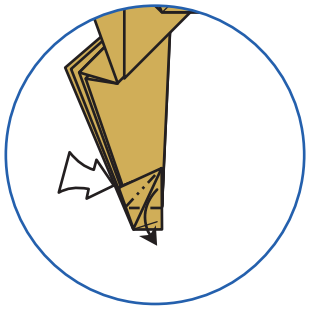
156. Squash-fold.



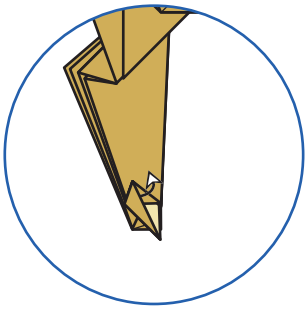
157. Fold the corner using a fold-line which is directly above the folded edges on the lower layers.



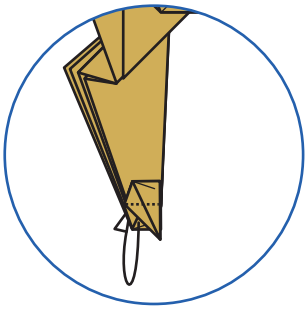
158. Pull one layer as far as it will go.



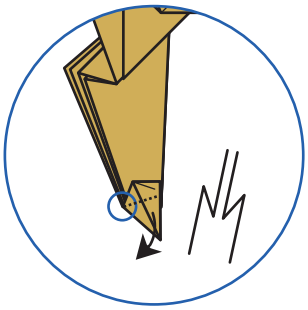
159. Swivel-fold the corner down.



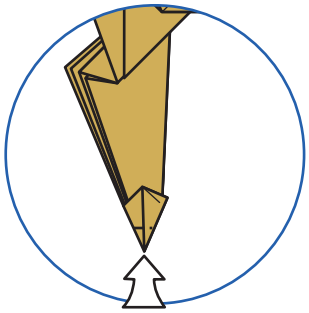
160. Pull both layers as far as they will go.



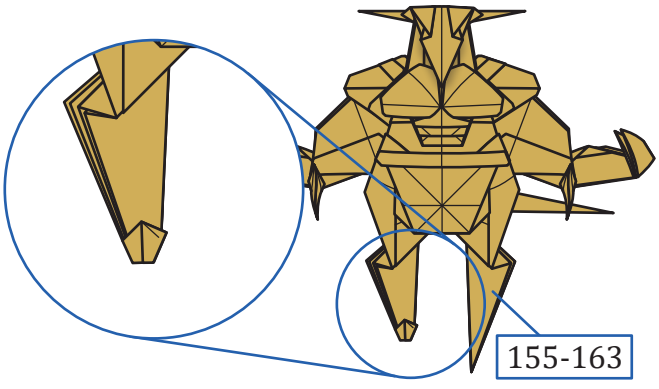
161. Mountain-fold the second flap behind.



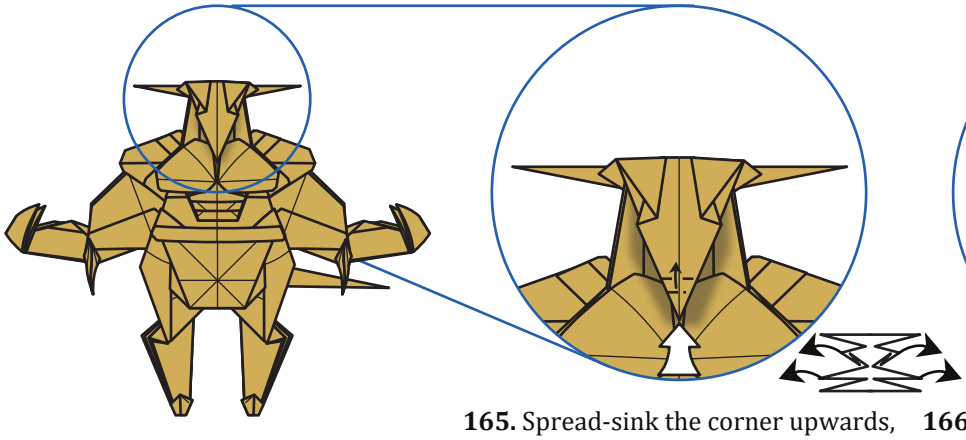
162. Twist the region so that the corner points downwards, pivoting about the circled point.



163. Reverse-fold the tip.

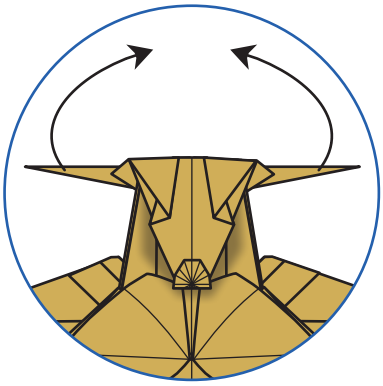


164. Repeat steps 155 to 163 on the right leg.

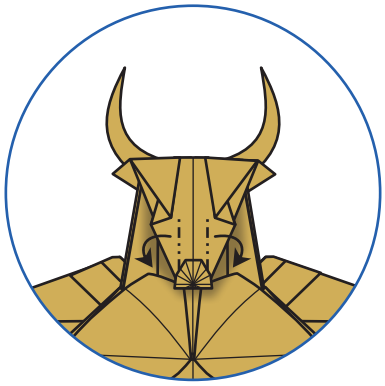


165. Spread-sink the corner upwards, pulling the middle layers sideways so the region lies flat.

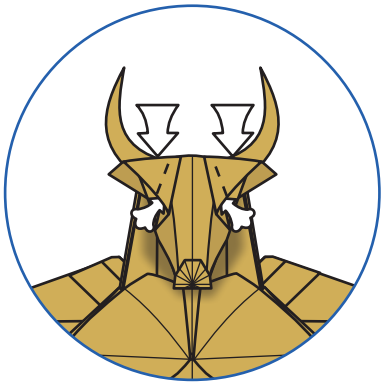
166. Mountain-fold the bottom part of the region underneath.



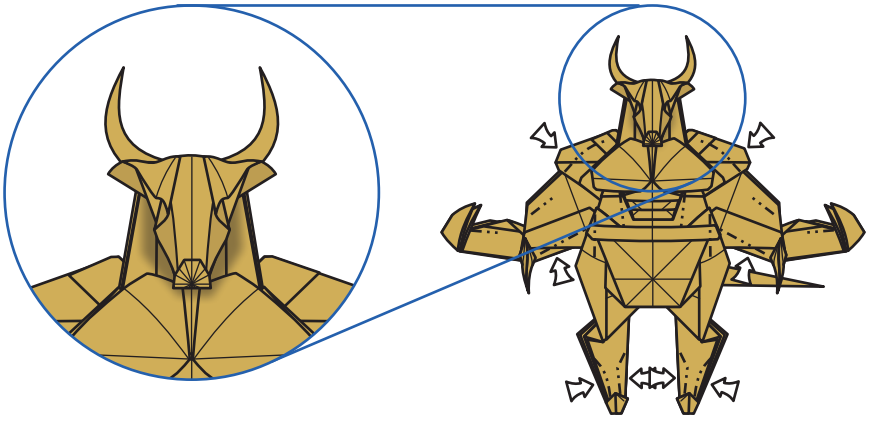
167. Curl the horns upwards.



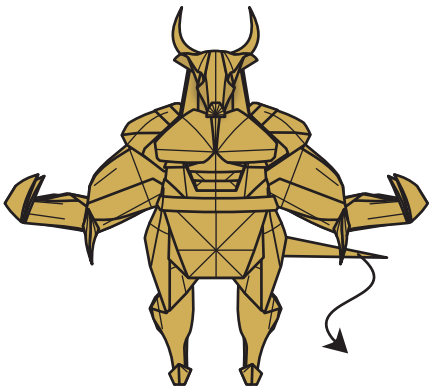
168. Curve the head with mountain-folds.



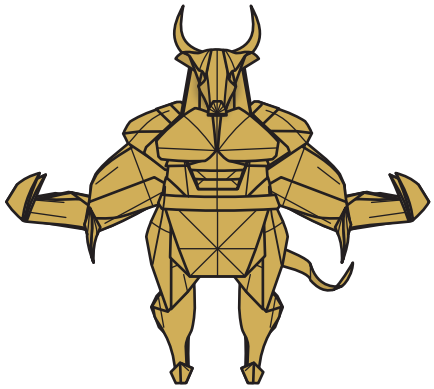
169. Open the eyes and shape the ears.



170. Shape the muscles on the arms, legs, and torso.



171. Bend the tail. You can use this as a third point of contact to help the model stand.



A tall tale

Sometimes origami designers tell a small lie. We declare that our designs are meticulously crafted, describing all the design techniques that have been used, and we give the impression that it takes hours of intellectually intensive work to make a little paper model. This provides a nice story because it encourages the reader that if they merely study the techniques for long enough, then they too will have the superpower to create their own origami designs. In fairness, not all designers are guilty of this, and for others, it is actually true.

However, this misses out on an important fact. Although learning techniques is a big part of design, no designer consciously thinks through all of the aspects of their designs. Yes, it could be said that it's the subconscious mind working – our 'intuition' – but I think designers need to accept some vulnerability and admit there are many unplanned parts of the process. We hide those frequent moments of unintended discovery, perhaps because it shatters the illusion that origami design can be boiled down to pure mathematical rules that perfectly dictate how all features fall into place. But these moments are my favourite of all – they feel like unearthing some wonderful secret, and it's a genuine joy to be the one who stumbles across it. It's as though you are working in tandem with the paper, being led by it into the form it wants to take rather than battling to force it into a specified shape.

This isn't to say that it would be impossible to number crunch each of these revelations into existence. Modern software is incredibly powerful and improving steadily, but that simply isn't where the best origami experiences come from (and thankfully, humanity often invests computing power into more noble endeavours than making paper figures). If you want to find these joyous moments for yourself, I can offer no better advice than to suggest you try designing. Like with all education, there is no substitute for sheer practice, and the creative journey should be emphasised much more than the destination. But as a teacher myself, I know that the appealing narrative of quick fixes will always rear its ugly head in every corner of academic learning because investing the necessary time is challenging.

Or, to summarise the above with only 10% of the word count: origami is an art as well as a science, so let's not pretend otherwise. There is no ultimate algorithm for all origami design, and if there ever is one, I believe that will spoil most of the fun.

Changing your fortunes

Having these occasions of good fortune isn't the same as the well-known 'accidental' (or 'trial-and-error') method of design that comes about by doodling. It isn't randomness waiting to jump out at the folder, but something that is tempted out of the paper by careful usage of other methods. Besides, I'm not talking about designing a whole model by chance, but making the most of any brief epiphanies along the way.

Just as important as providing the opportunity for these moments is the ability to identify and use them. Again, experience is a vital asset because it means pleasing structures will be familiar and can be recognised easily.

To see what I mean, it would help to see an example of what I'm talking about: the journey of designing the Minotaur showcases a series of these lucky breaks.

An outlandish adventure

Most of my designs start from a position of intentionality: I know the subject I'm aiming for (with reasonable room for variations within the subject). Since I'm being honest, I'll admit that I'm not completely certain this was the case for the Minotaur. What I am sure of is that I began by playing around with some simple 22.5° shapes in an attempt to get a humanoid figure. This was no doubt part of my usual rebellion against the horde of box-pleated humanoid designs. Box pleating is tempting for humanoids for many reasons:

- No traditional bases have the appropriate arrangement of flaps, whereas there are established, efficient arrangements with box pleating.
- Box pleating allows the designer to specify the length of limbs precisely.
- Box pleating provides ample pleats which can create details such as on the face or fingers.
- It's often relatively easy to graft new flaps onto box-pleated models.
- The almost rectangular limbs and torso can be approximated by pairs of parallel lines.

It's the 'almost' in that final point which is the Achilles heel for many box-pleated humanoids. Box-pleated features usually appear too rectangular and inorganic for my liking (this is often overlooked on other subjects, but human bodies are too familiar to get away with this). Tapering a rectangle so that it gets thinner at one end doesn't work too well either, because it results in the paper having more layers in places where it should actually be thinner.

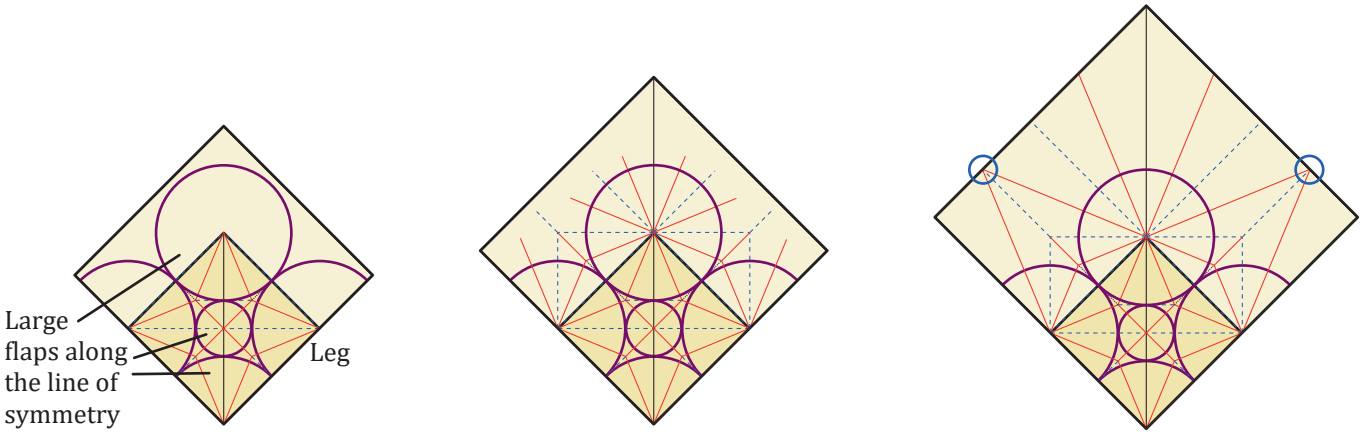
This is why I'm always delighted when I see a 22.5° humanoid design. But this switch in design geometry isn't without drawbacks – namely the other four bullet points above! I'm obliged to say that there's nothing incorrect about using box pleating, and there are often other very good reasons to do so. I just feel that we need more variety with our complex and supercomplex subjects, particularly humanoids.

Taming the beast

So how do we mitigate some of these issues when using 22.5° geometry? To ensure we have enough details, it will help to have a number of flaps along the front of the model, which will be versatile if they are sufficiently large. We can point-split some of them to get smaller details where needed too.

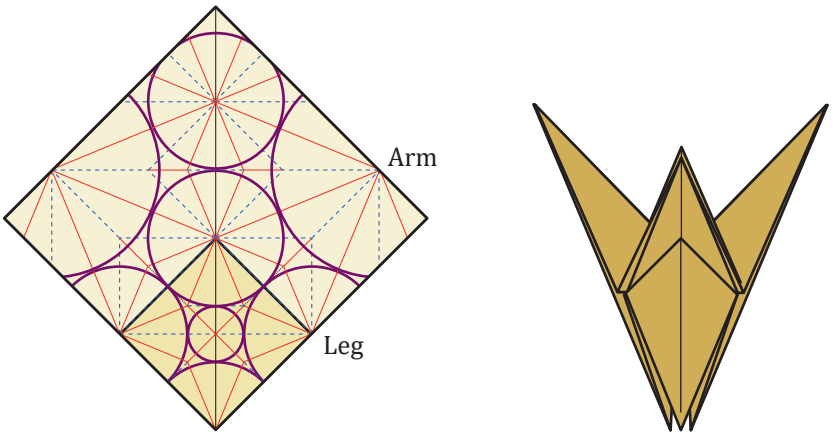
So, the task isn't too daunting; we just need a base with some large flaps at the front. Even if we can't start directly from a traditional base, we can graft onto one easily enough to build up to what we need. As usual, it makes sense to start with the largest flaps, which for a humanoid are normally the legs. A Bird Base placed at the bottom of a square with diagonal symmetry seems like a good starting point then – see the image below.

Then we can extend creases radially into the grafted region as in the central image below. The easiest layout will have these lines extend all the way to the raw edge. But how far will this be exactly? The image on the right shows the natural upper limit for the size of the grafted region, because it's the largest option before the creases start to overlap. This is a helpful arrangement to consider because it determines the locations of all creases. In fact, this exact structure is seen relatively frequently in complex origami designs.



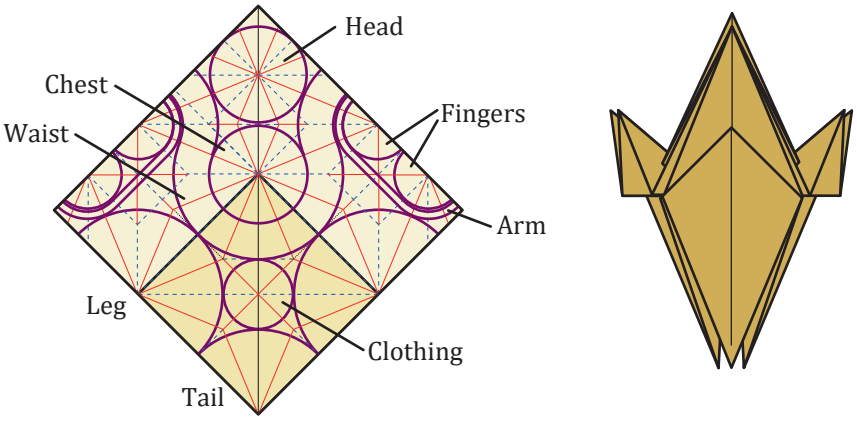
Left: Bird Base in the corner of a square.
Centre: Extending creases radially into the grafted region.
Right: The largest graft possible without the creases overlapping at the circled points.

By folding this crease pattern, we find that the base has some promise. The circled points on the previous page are not on the line of symmetry, so if we use these as flap centres, we will have a non-axial base. This is a good thing for making these flaps into arms because it allows sufficient width for the shoulders (many box-pleated, axial humanoid bases lose paper because the arm flaps need to traverse the distance between the axis and where the arm should actually begin). We can again extend some lines radially, this time from the tips of these arm flaps. This creates quite a pleasing crease pattern, shown below.



Left: Extra creases now extend radially from all flaps.
Right: The folded base.

This base is a nice find, but for making a humanoid, there's a problem: the arm flaps are too long (even allowing for some artistic license with some top-heavy fantasy creatures). So we shouldn't have extended the graft quite this far. Let's backtrack and see what happens when we make the grafted region a bit smaller but keep the basic pattern the same.



Left: The corresponding pattern for a smaller graft. Several flaps are now tentatively labelled.
Right: The folded base.

Using a smaller graft causes the tip of the arm flaps to have multiple subflaps because the two mountain creases which previously met now have some extra distance between them. This distance is split into just two points here for simplicity, but could just as easily be divided into three or more flaps. This is a wonderful discovery because we can get fingers (or some other details on the hand) without deliberate pleats, extra grafting, or point splitting – this property emerges quite by accident!

But we've gone too far in the other direction: the arm flaps are now too short. So the ideal graft that creates arms of the right length is somewhere between these two extremes.

But it's not just the arms that will change length if we change the size of the graft. As the size of the grafted region increases:

- The length of the arms increases
- The size of the chest flap increases
- The width of the waist river decreases
- The length of the fingers decreases
- The size of the head decreases

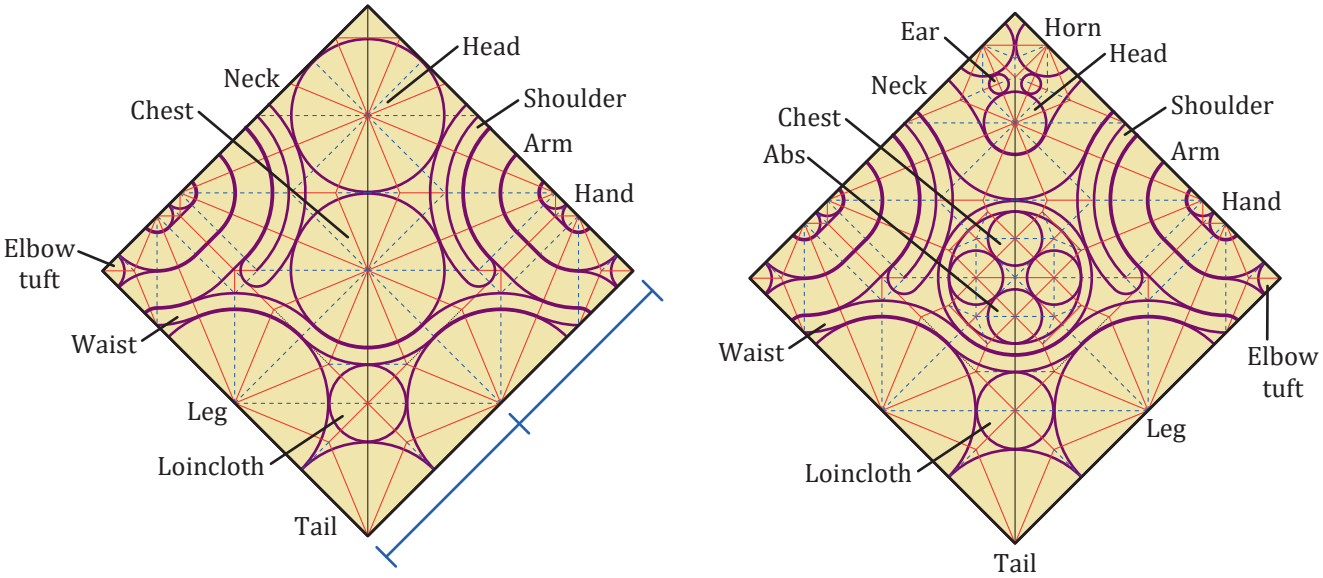
At this point, we might wonder whether an optimal point even exists; for example, it could be that to get sufficiently long arms, we'd be forced to make the flap for the head too small. This sort of constraint often happens when we tie multiple references to one variable, which is the graft size in this case. In mathematical lingo, we say there is only one **degree of freedom**. Having one degree of freedom is often fine when it only affects a couple of features, but there are five here.

What's more, we'd ideally have a non-arbitrary way of determining the graft size so that we get a simple folding sequence to find the references. Also, to fulfil our desire for aesthetic satisfaction, we'd like all creases to match nicely with some of our existing 22.5° geometry in some way. Are we asking too much?

Following the thread home

Here's another marvellous discovery: an ideal arrangement appears by using perhaps the simplest possible reference – a point exactly halfway along the edge of the paper.

The chest flap turns out to be suitable for a four-point split, with enough paper to make defined muscles. The head also has a convenient amount of paper to create horns and other features. Additionally, the unused paper at the raw corners turns out to be halfway along the arm flaps and can be used for a small detail like a tuft of hair at the elbow.



Left: A humanoid can be made by making the width of the graft exactly the same size as the initial bird base. Right: The final crease pattern for the Minotaur.

It would have been even nicer if the flap for the loincloth happened to come from the raw edge to allow for a colour change (though as this was one of the few flaps I planned in, I've only myself to blame here). There's a small amount of inefficiency with needlessly long rivers around the chest and shoulders, but since this adds bulk to the torso, it could be argued this is no bad thing.

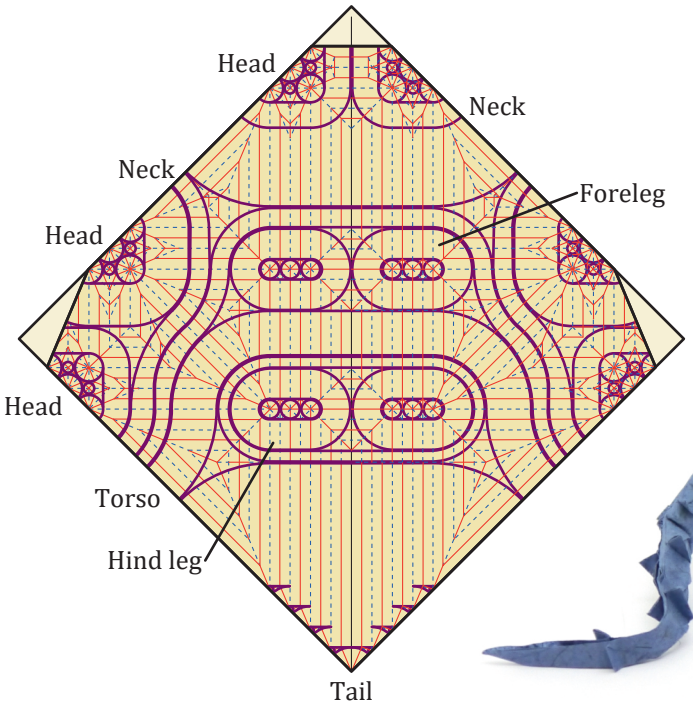
All of these thoughts took place in a matter of only a few minutes, and not necessarily in the order presented here. This Minotaur had an incredibly quick design process, not because of any particular skill of mine but because of the sheer number of coincidences that all fell into place at once. But in the words of a 19th-century saying: "The more I practise, the luckier I get".

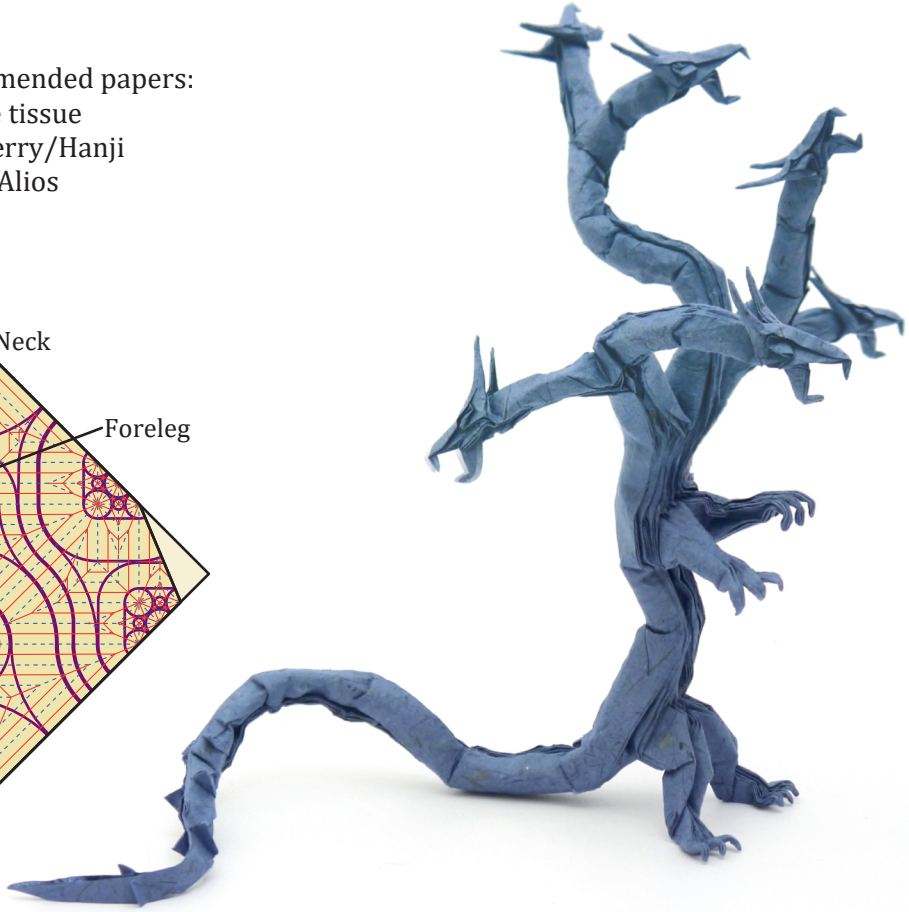
Hydra

First time: 60cm/24''

Paper preferences:
- Ultra thin
- Shapeable

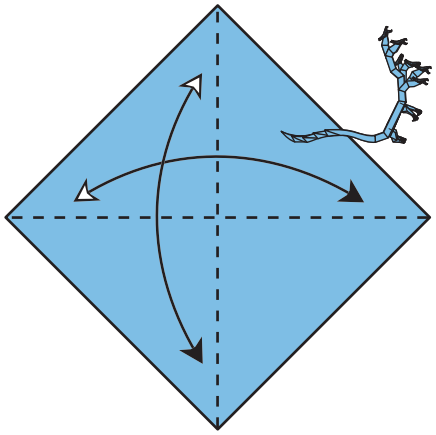
Recommended papers:
- Single tissue
- Mulberry/Hanji
- Kraft Alios



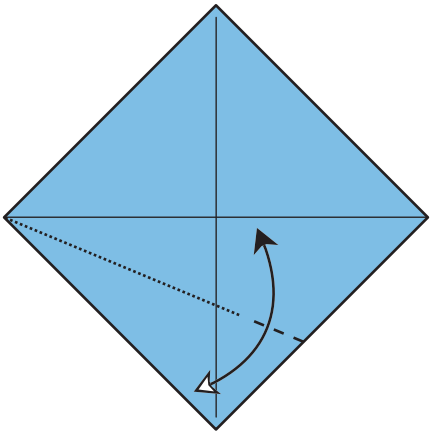


Each head is relatively detailed and folded in the same way, so there are a lot of repeated steps in these diagrams, including nested repeats (repeats within repeats within repeats etc.). Keep careful track of the steps you are being asked to repeat and the step you need to return to so that you don't get lost.

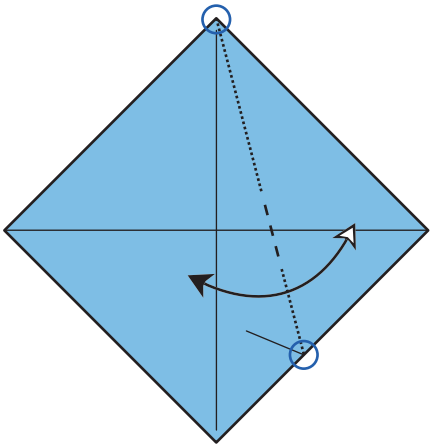
Start body colour side up.



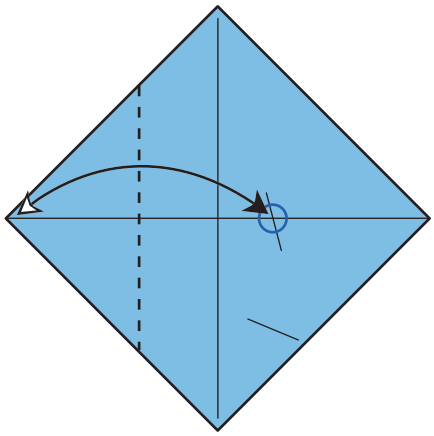
1. Fold and unfold the diagonals.



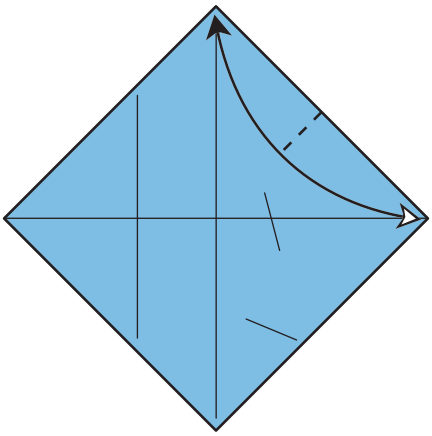
2. Fold the bottom left raw edge to the diagonal, mark firmly only at the bottom-right raw edge, then unfold.



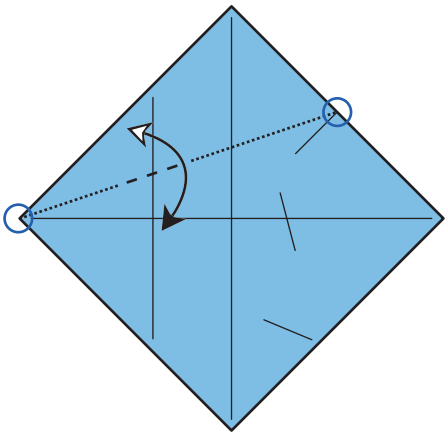
3. Make a fold-line which connects the circled points, mark firmly only along the horizontal diagonal, then unfold.



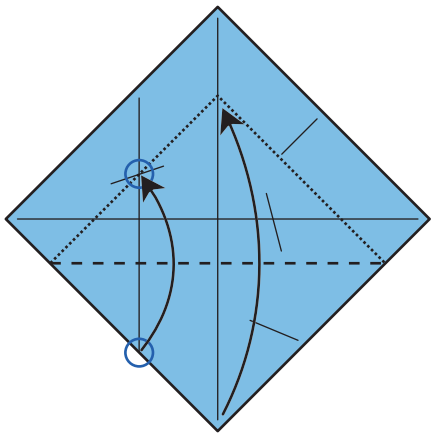
4. Fold the left raw corner to the circled point, then unfold.



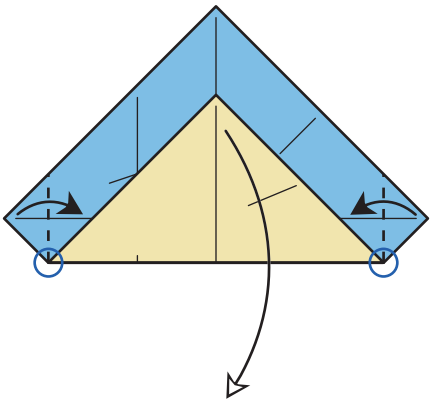
5. Fold the right raw corner to the top raw corner, mark firmly only at the top right raw edge, then unfold.



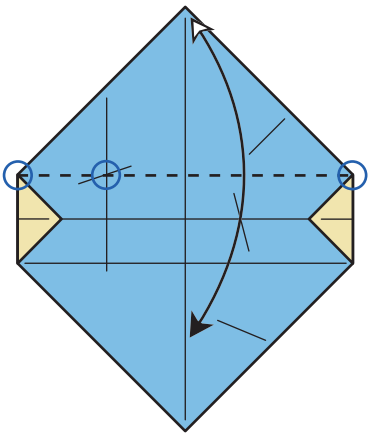
6. Make a fold-line which connects the circled points, mark firmly only over the crease made in step 4, then unfold.



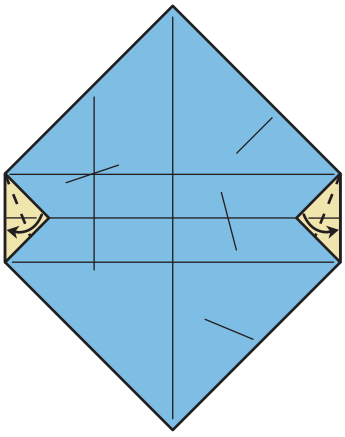
7. Make a horizontal fold-line so that the lower left raw edge touches the circled intersection.



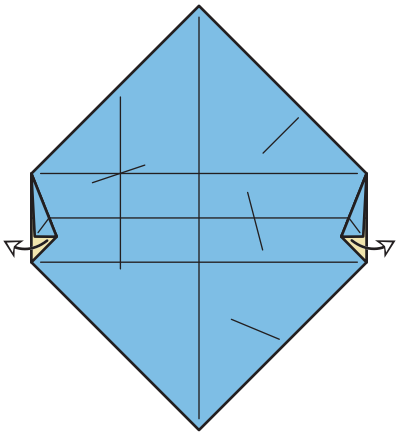
8. Fold the raw corners in along vertical fold-lines which go through the circled points. Then unfold step 7.



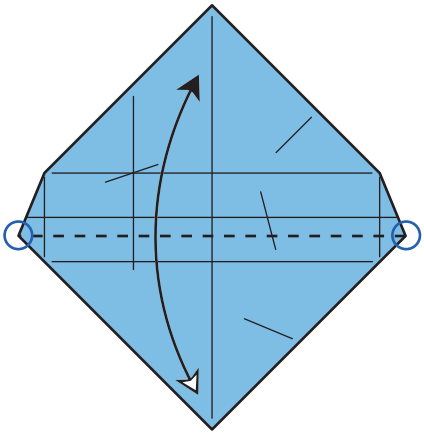
9. Fold and unfold a horizontal fold-line that connects the top of the white triangles (and it should also go through the circled point in the middle of the paper).



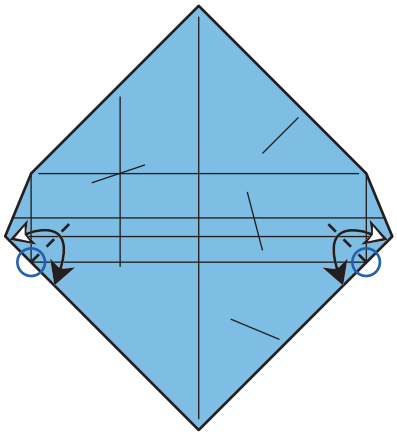
10. Fold the upper raw edge of the white triangle down to the folded edge on each side. Treat the raw corners as though they are stuck to the next layer for the rest of the model.



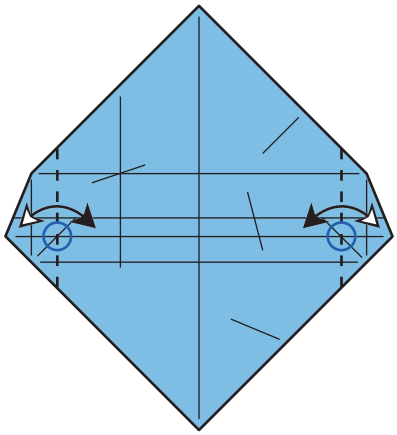
11. Unfold step 8 (but not step 9).



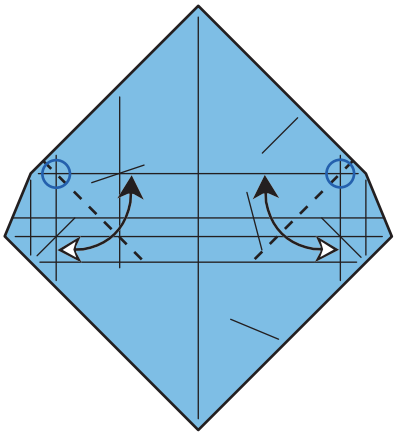
12. Fold and unfold.



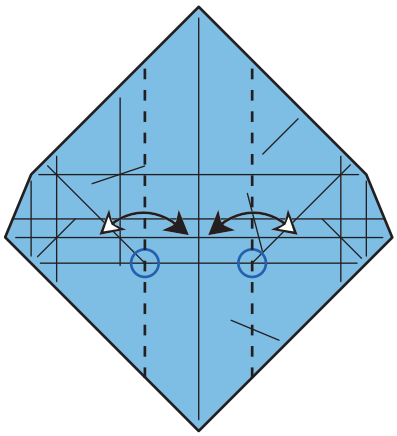
13. Fold and unfold two small angle bisectors.



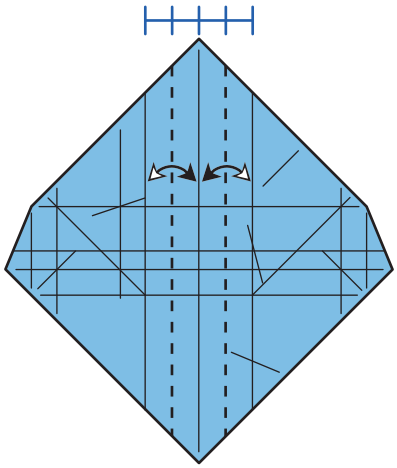
14. Fold two vertical lines through the circled points, then unfold.



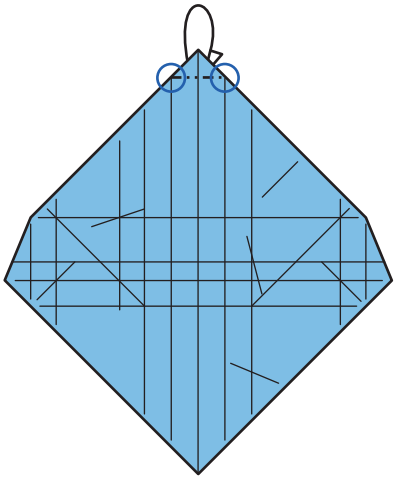
15. Fold two diagonal lines through the circled points, then unfold.



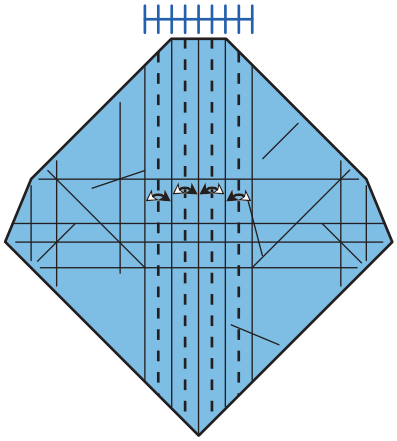
16. Fold two vertical lines through the circled points, then unfold.



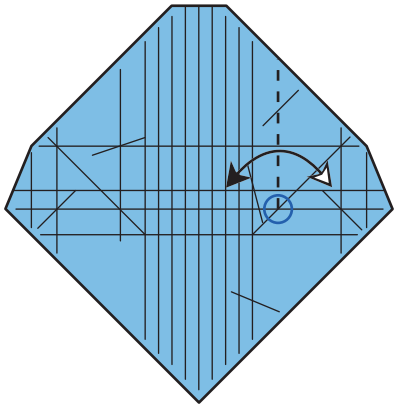
17. Fold the creases you just made to the centre and unfold.



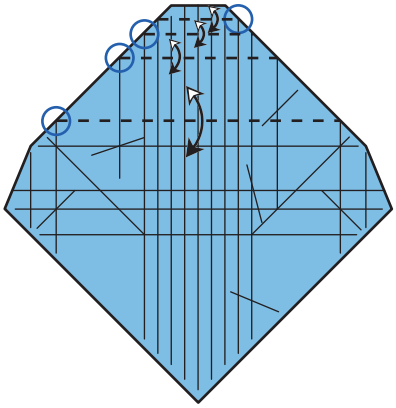
18. Mountain-fold the raw corner behind using a horizontal fold-line through the circled points.



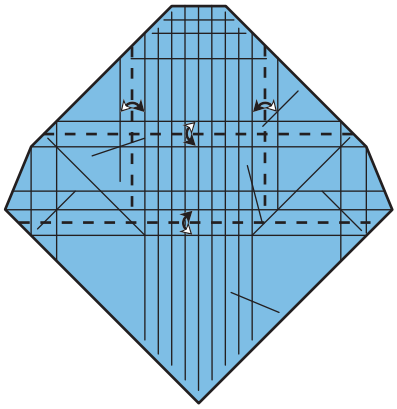
19. Fold and unfold halfway between the creases shown.



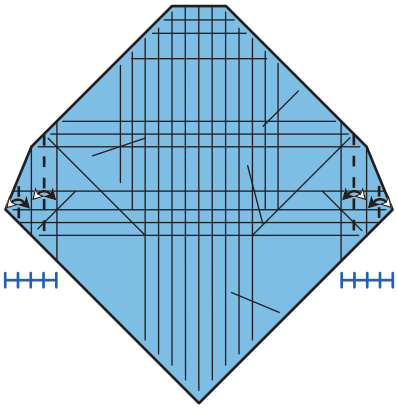
20. Fold and unfold a vertical line that goes through the circled point. (You already made the equivalent fold on the left in step 4.)



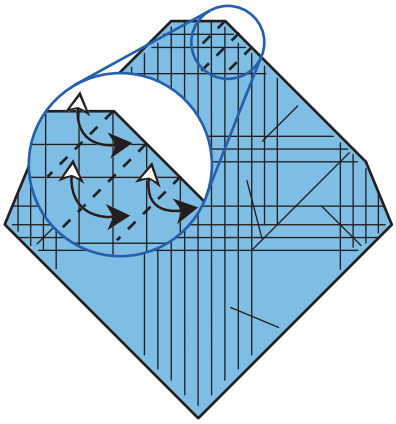
21. Fold four horizontal lines through the circled points, then unfold.



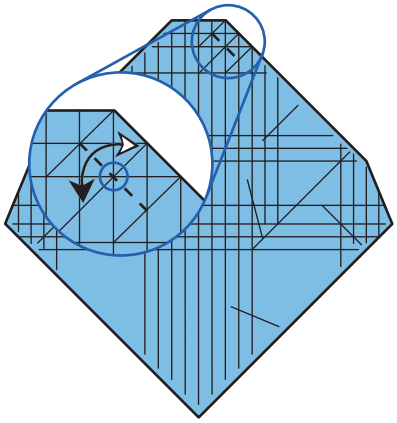
22. Fold and unfold halfway between four pairs of parallel lines.



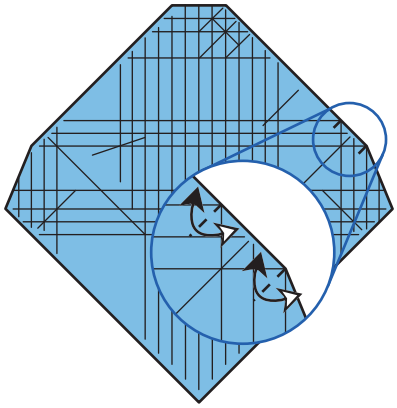
23. Fold and unfold the regions shown into quarters.



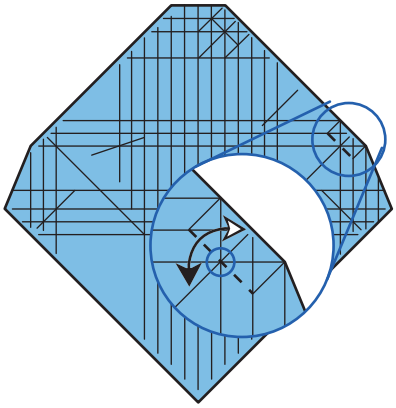
24. Fold and unfold three diagonal lines.



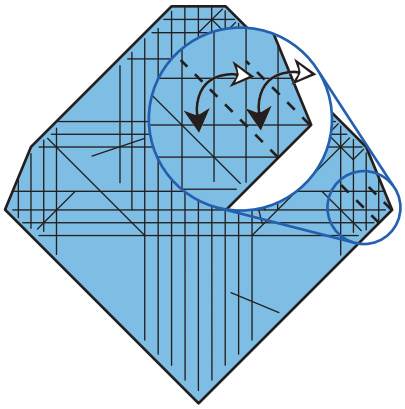
25. Fold and unfold a diagonal line through the circled point.



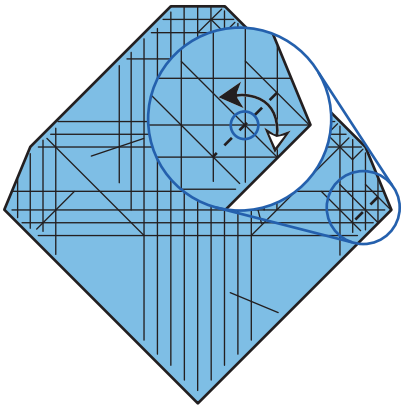
26. Fold and unfold two diagonal lines.



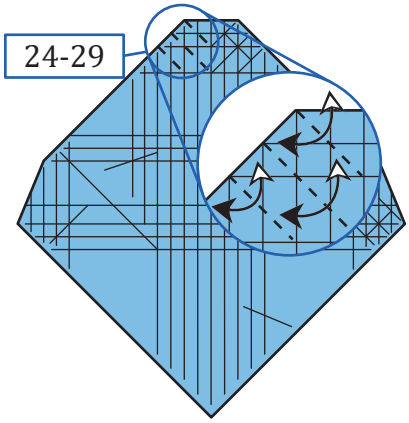
27. Fold and unfold a diagonal line through the circled point.



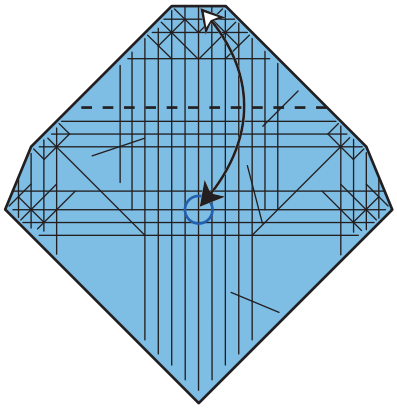
28. Fold and unfold two diagonal lines.



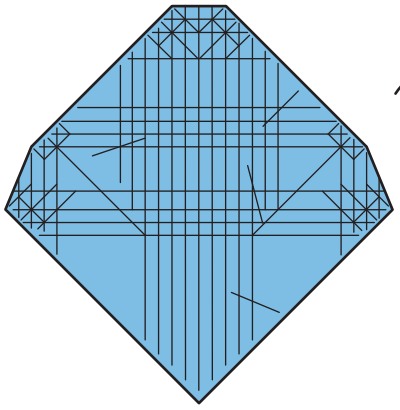
29. Fold and unfold a diagonal line through the circled point.



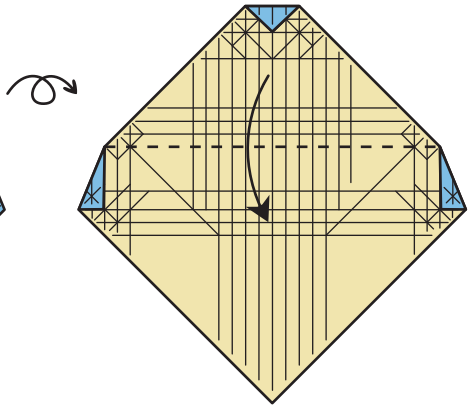
30. Repeat steps 24 to 29 on the left.



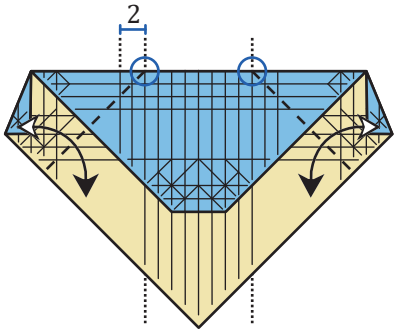
31. Fold the centre of the top edge to the circled point, then unfold.



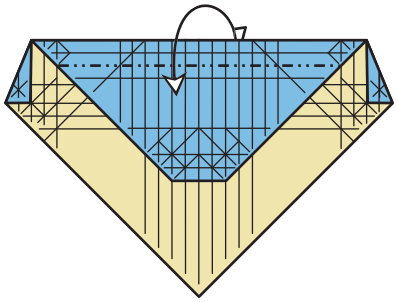
32. Turn the paper over. Some creases will no longer be shown.



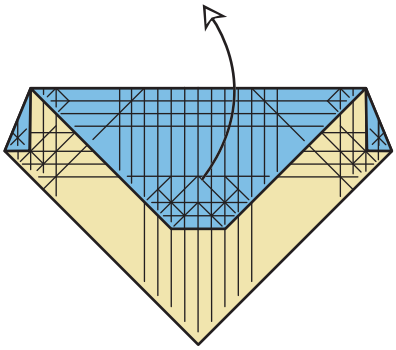
33. Fold the top section down.



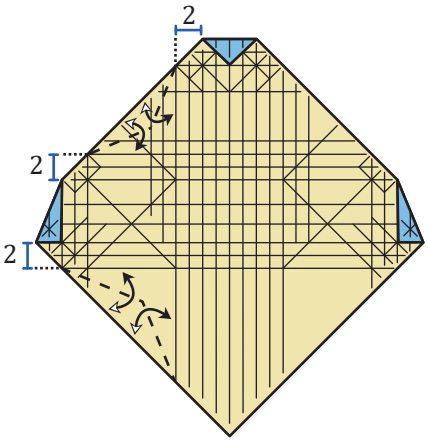
34. Fold and unfold.



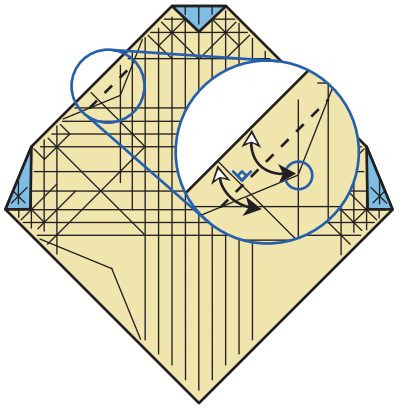
35. Make a **mountain fold** along an existing line to transfer the crease to the far layer, then unfold.



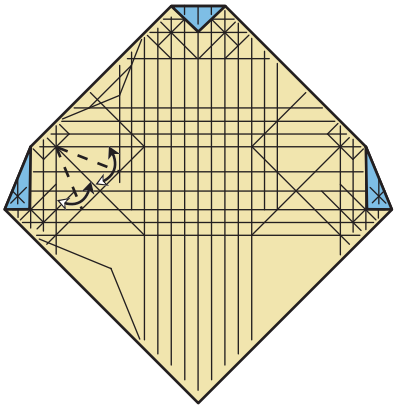
36. Unfold step 33.



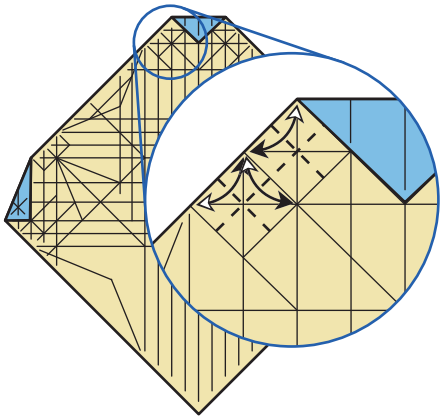
37. Fold and unfold four angle bisectors.



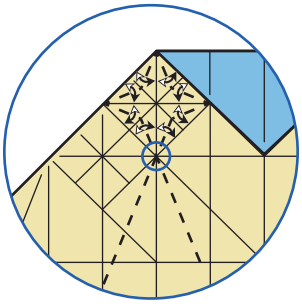
38. Fold the raw edge to the circled point along a fold-line which is parallel to the raw edge, then unfold.



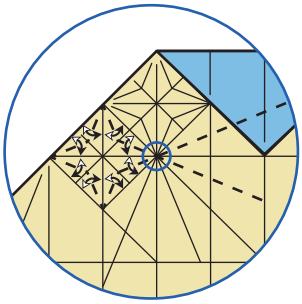
39. Fold and unfold two angle bisectors.



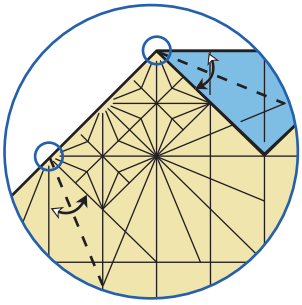
40. Fold and unfold three lines.



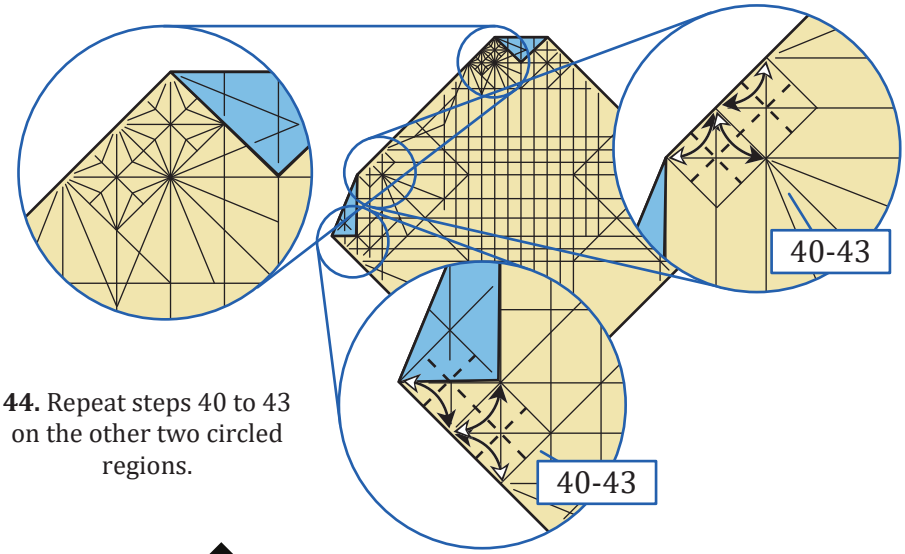
41. Fold and unfold 8 angle bisectors. Extend two of the fold-lines from the circled point into the paper, as shown.



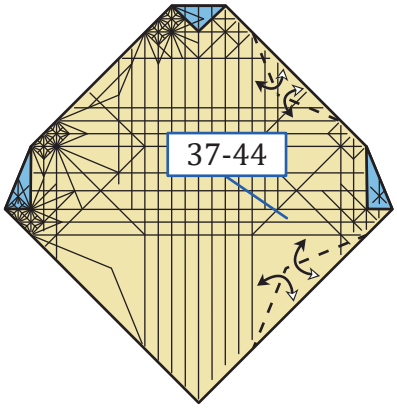
42. Fold and unfold 8 angle bisectors. Extend two of the fold-lines from the circled point into the paper, as shown.



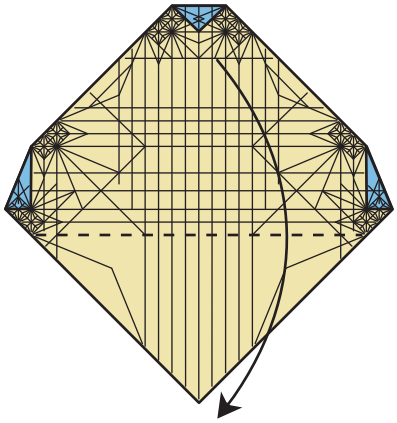
43. Fold and unfold the remaining angle bisectors around the circled intersections.



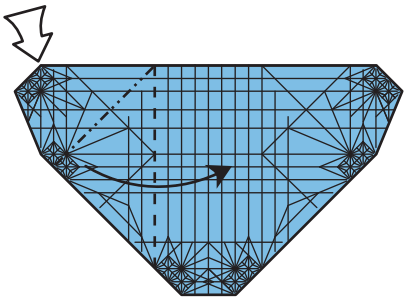
44. Repeat steps 40 to 43 on the other two circled regions.



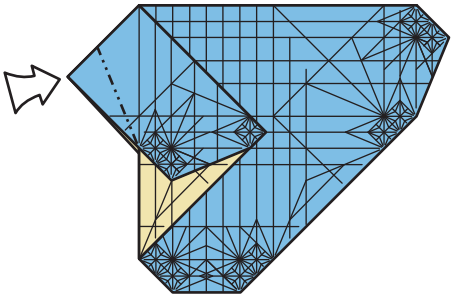
45. Repeat steps 37 to 44 on the right.



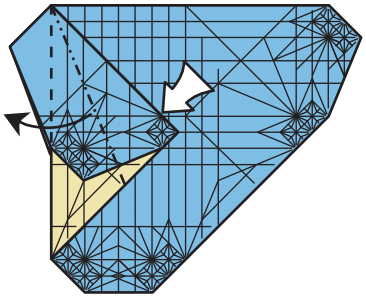
46. Fold the top section down.



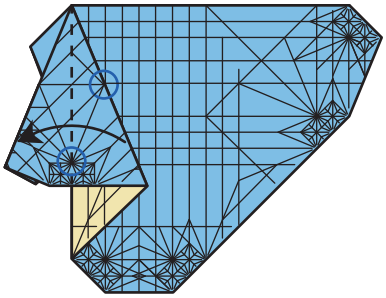
47. Squash-fold the edge.



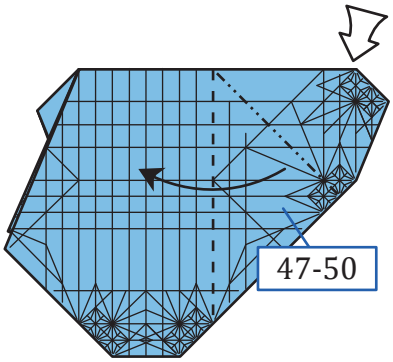
48. Reverse-fold the raw edge using existing creases.



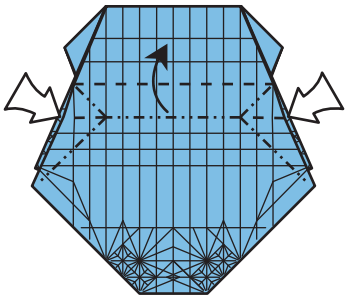
49. Squash-fold the edge.



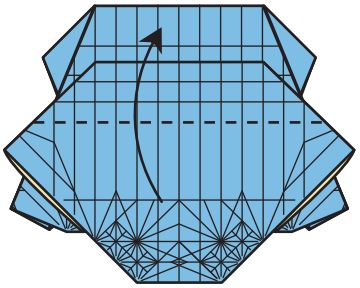
50. Note the crease between the circled points – you will use this in step 52. Fold one flap to the left.



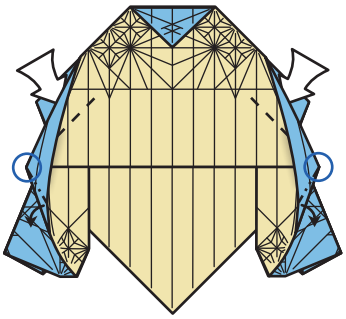
51. Repeat steps 47 to 50 on the right.



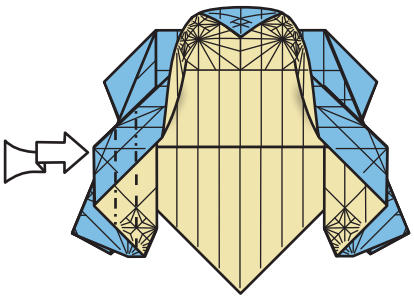
52. Push the sides in and bring the horizontal mountain upwards using existing creases. Use the hidden lines noted in step 50.



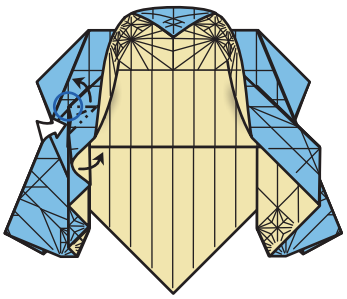
53. Fold the near section up using an existing valley fold. The paper won't lie flat until after step 57.



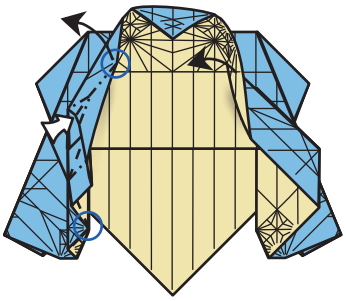
54. Flatten the sides by making new mountain folds, which end up vertical and in line with the circled points. The new valley folds are aligned with the folded edges directly beneath them.



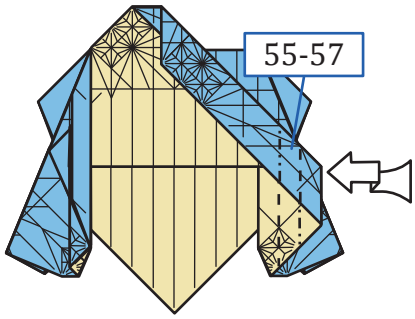
55. Sink the left edge in and out. The new folds on the near layer should only be made lightly.



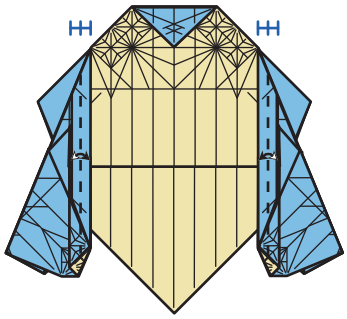
56. Pivot the top layer of paper anticlockwise a little about the circled point.



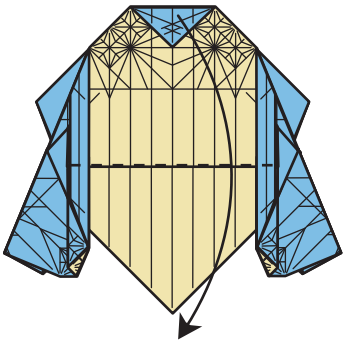
57. Stretch the raw edge between the circled points and flatten the paper using existing creases.



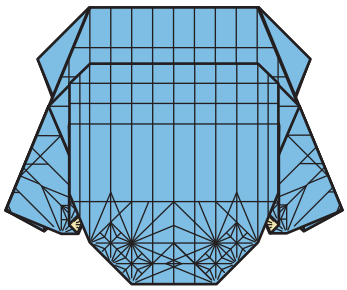
58. Repeat steps 55 to 57 on the right.



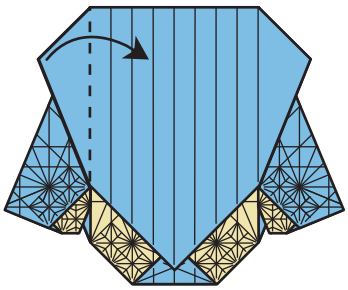
59. Fold one set of narrow connected flaps in half on each side, then unfold.



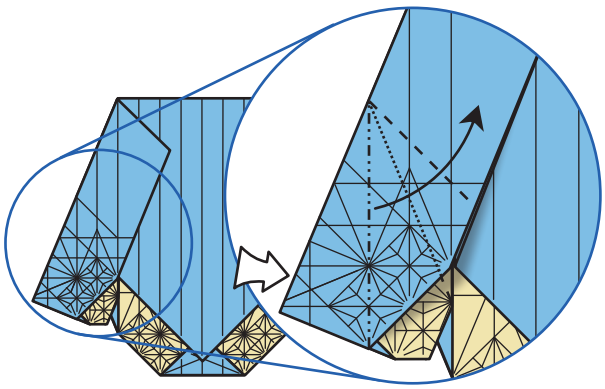
60. Fold the near flap down.



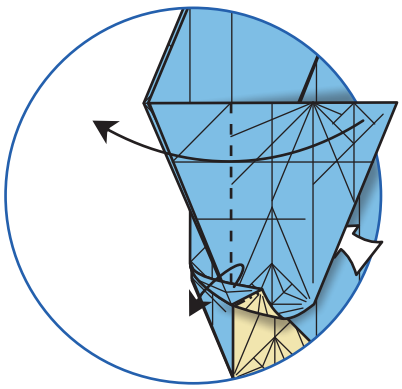
61. Turn the paper over.



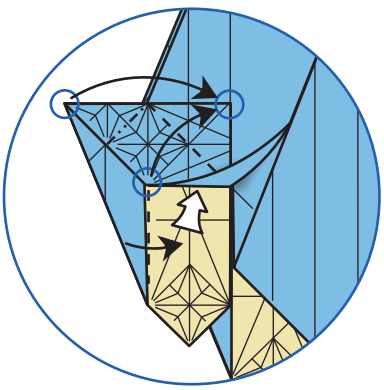
62. Fold one flap to the right.



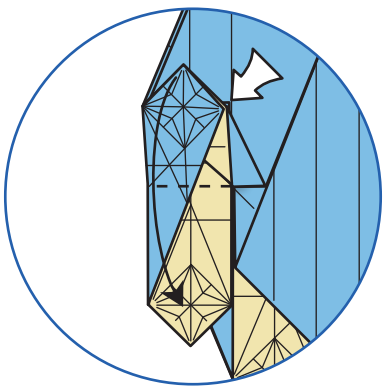
63. Pinch the vertical mountain fold-line and swivel-fold it up and to the right so that it becomes horizontal. Don't flatten the paper at the bottom.



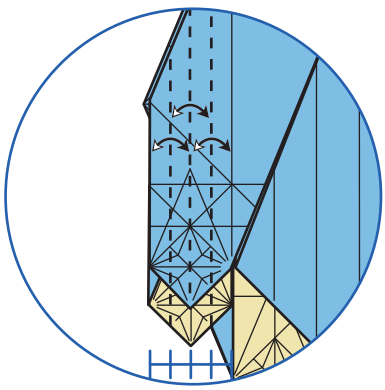
64. Swivel-fold the corner to the left using the vertical valley fold. Flatten the paper at the bottom, but the paper in the centre will not lie flat.



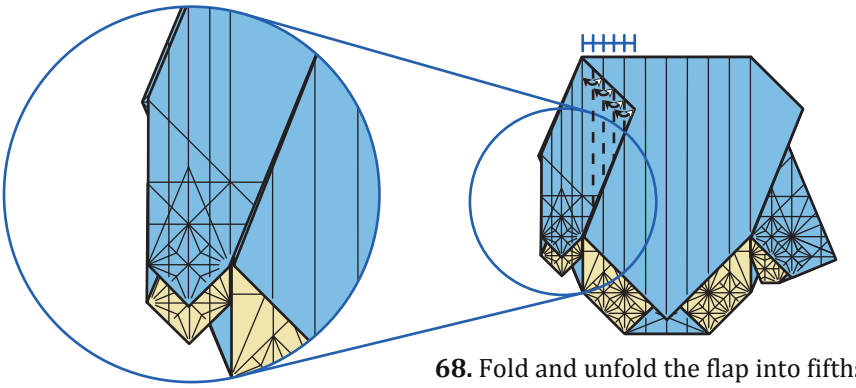
65. Swivel-fold to bring the circled corners together. The paper will lie flat after this.



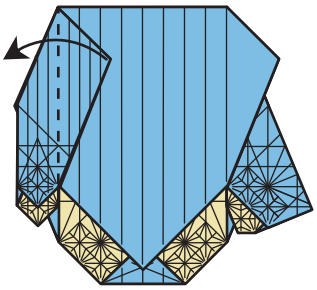
66. Swivel-fold the flap down.



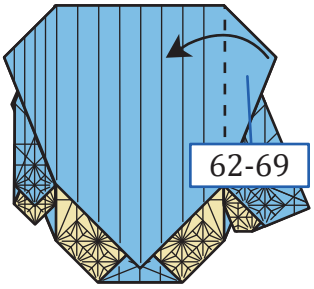
67. Fold and unfold the flap into quarters. Fold the visible white layer and all layers in front of it.



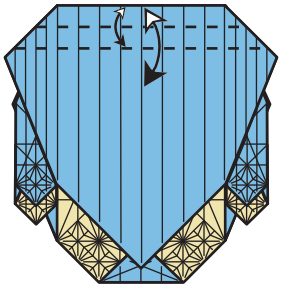
68. Fold and unfold the flap into fifths. (The existing vertical creases don't exactly line up with these new fold-lines, but they are a good approximation if you want to use them as a guide.)



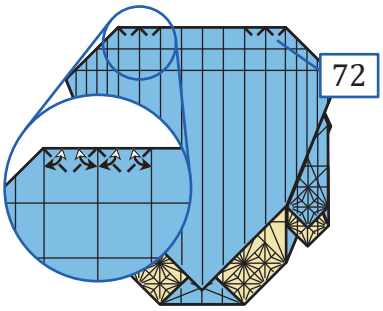
69. Fold the flap to the left.



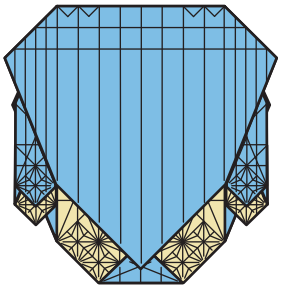
70. Repeat steps 62 to 69, flipping left and right.



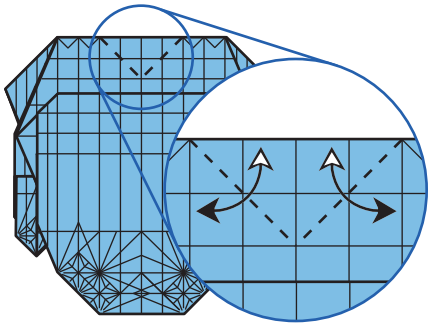
71. Fold and unfold the flap down using creases on the far layer to make new fold-lines on the nearest layer.



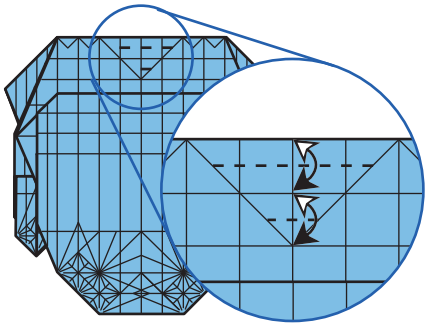
72. Fold and unfold four angle bisectors at the left of the top edge. Repeat on the right.



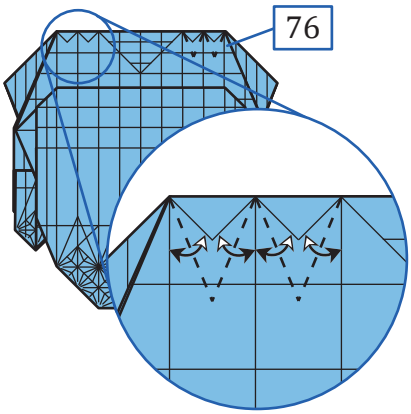
73. Turn the paper over.



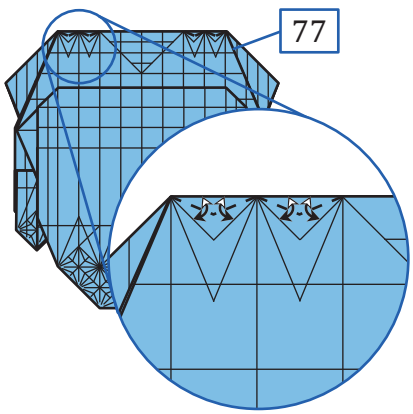
74. Fold and unfold two angle bisectors.



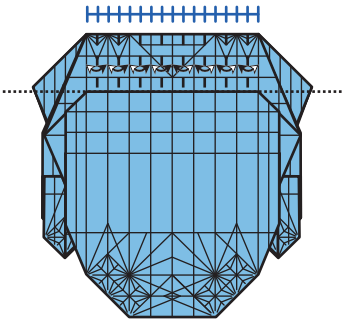
75. Fold and unfold two horizontal lines.



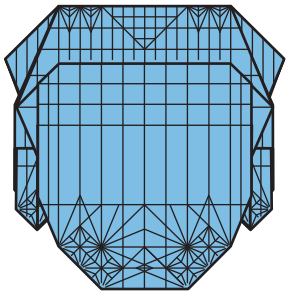
76. Fold and unfold four angle bisectors at the left of the top edge. Repeat on the right.



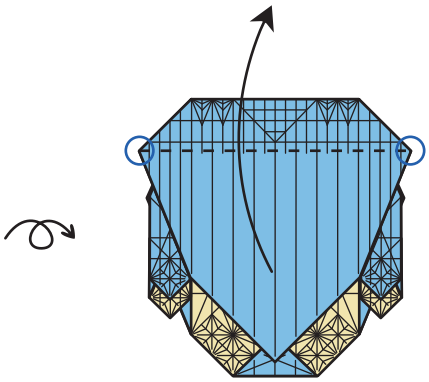
77. Fold and unfold four angle bisectors at the left of the top edge. Repeat on the right.



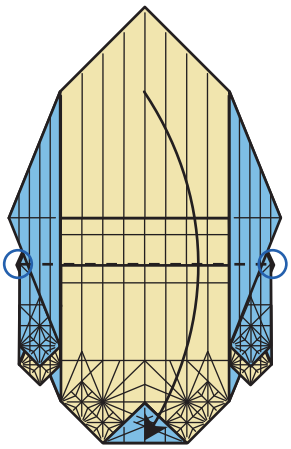
78. Fold and unfold eight new vertical lines to divide the top edge into sixteenths. Only fold in the region above the indicated folded edge.



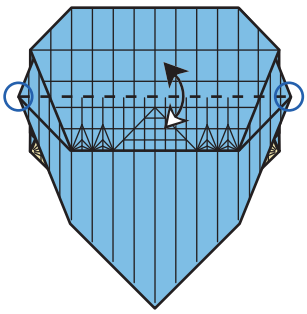
79. Turn the paper over.



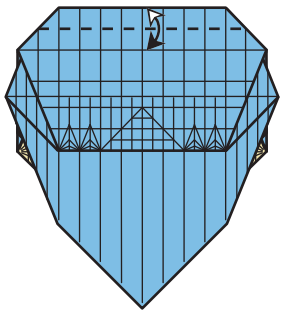
80. Fold the near flap up.



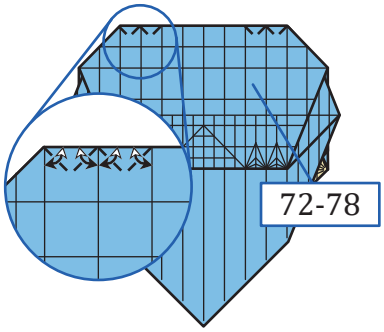
81. Fold the connected flaps down.



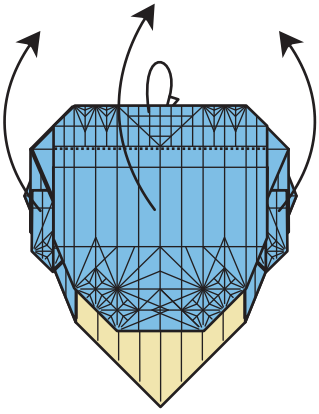
82. Fold and unfold.



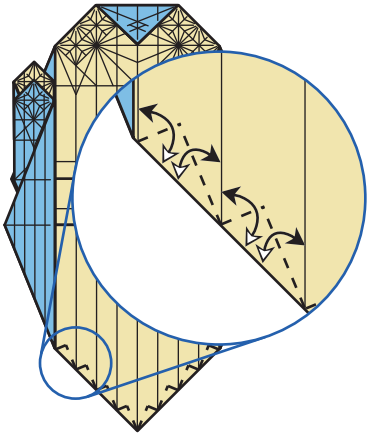
83. Fold the top edge to the nearest horizontal crease, then unfold.



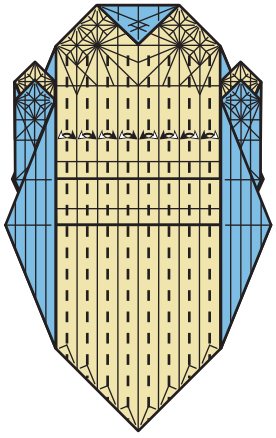
84. Repeat steps 72 to 78. (You may find it easiest to simply use the next image to fold these creases.)



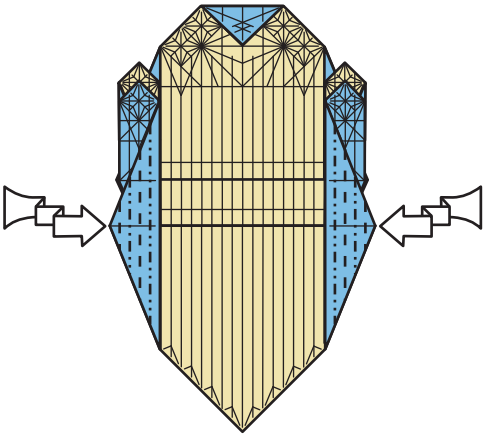
85. Fold the top edge behind, and swing the near layer and the connected flaps at the sides upwards.



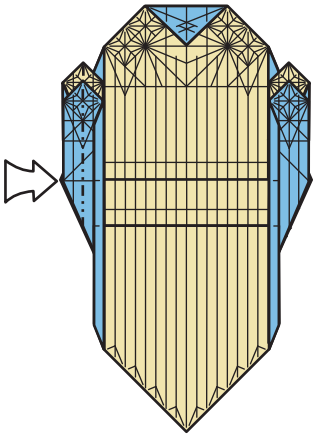
86. Fold and unfold two angle bisectors between each pair of vertical creases along the raw edge.



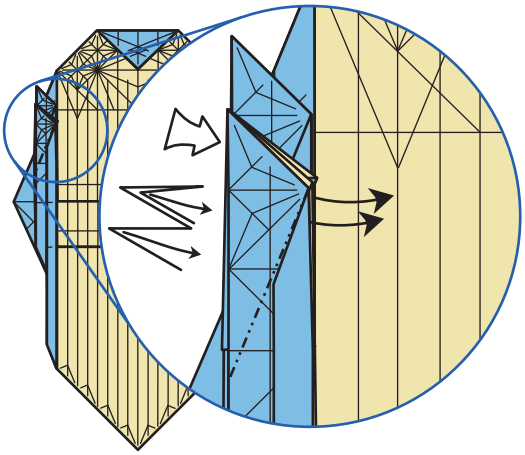
87. Fold and unfold halfway between the vertical creases (which are in the other direction to the creases made in step 78 – you need them to be bidirectional). Fold through all layers.



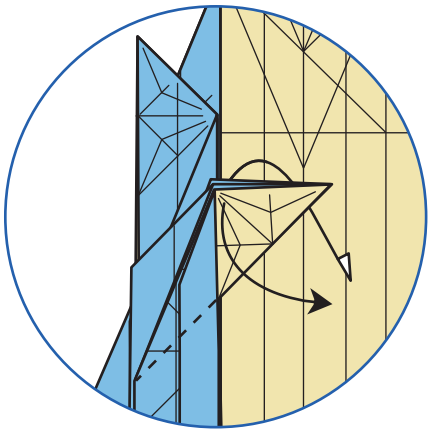
88. Open-sink the nearest flaps on each side in and out using existing creases (if you didn't make the folds in step 68 exactly you may have a very small corner sticking out on each side after this step, which is fine).



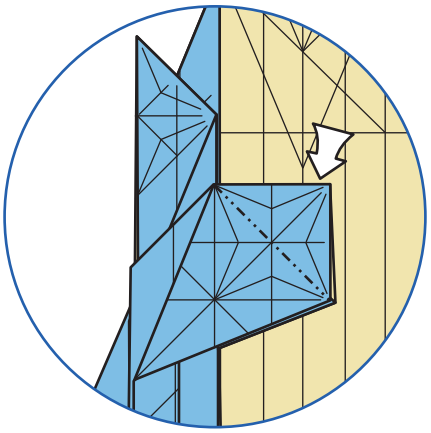
89. Open-sink the next edge on the left. Make sure to sink the whole ridge. You will need to partially unfold the paper to achieve this.



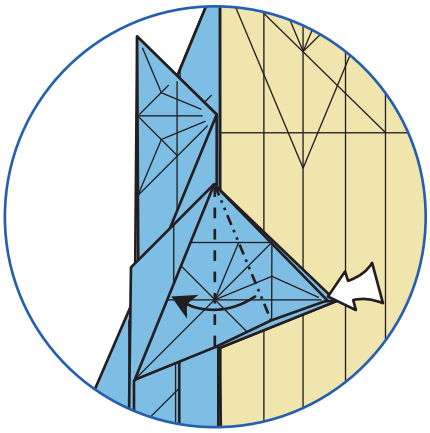
90. Mixed-reverse-fold the corner to the right along existing creases (while keeping the raw corner flat against the next layer, as noted in step 9). You will need to partially unfold the paper to achieve this.



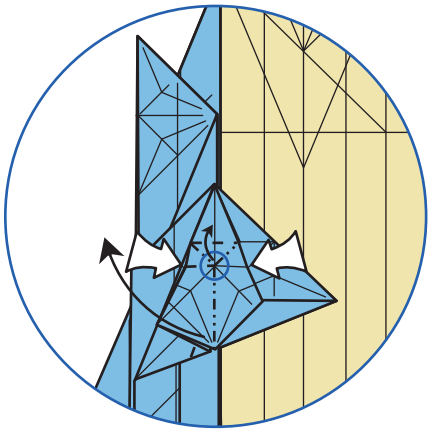
91. Fold the near edge down. Repeat with the edge on the other side of the flap.



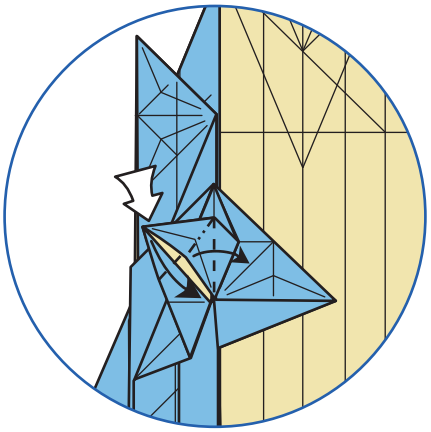
92. Reverse-fold the corner. Steps 93 to 97 involve making a small bird base on the square of the near flap.



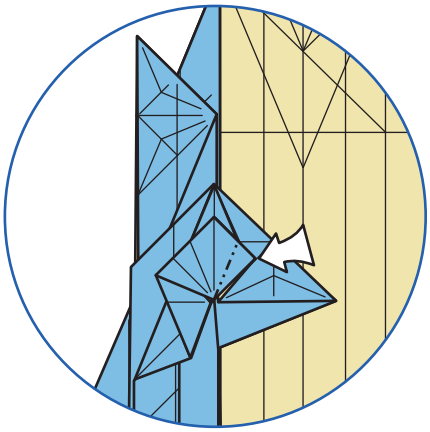
93. Squash-fold the edge. Don't flatten the paper firmly except along the existing creases.



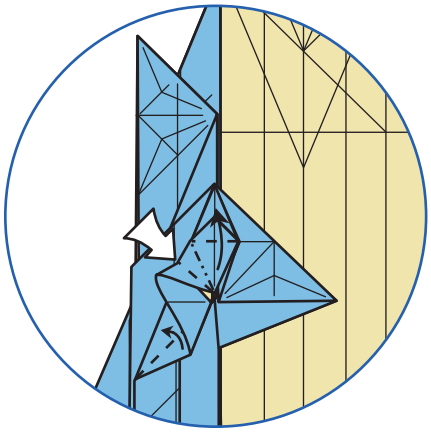
94. Squeeze the sides and bring the circled point upwards. Then flatten the corner to the left, but don't fold the paper firmly at the bottom.



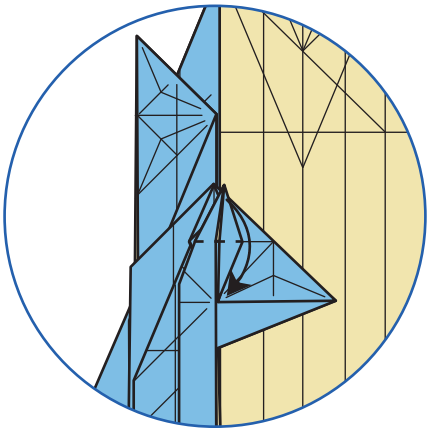
95. Squash-fold the corner.



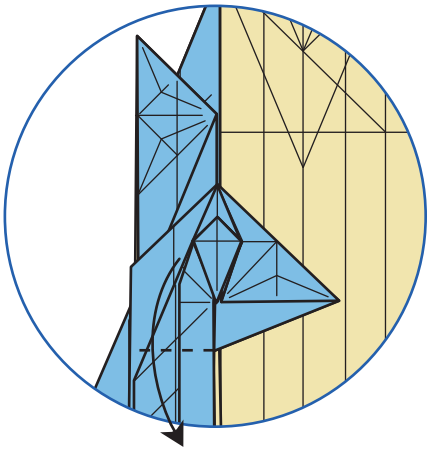
96. Reverse-fold using existing creases.



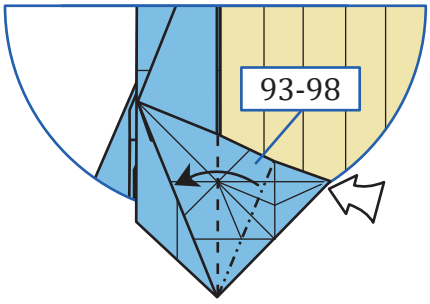
97. Swivel-fold the corner upwards. This will flatten the left edge using existing creases.



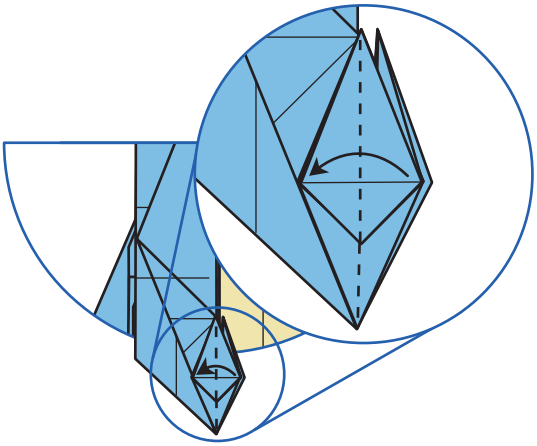
98. Fold the corner back down.



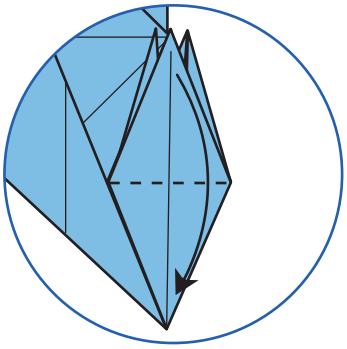
99. Fold the near flap down as far as it will go.



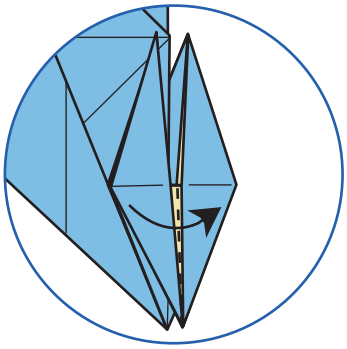
100. Repeat steps 93 to 98, flipping up and down.



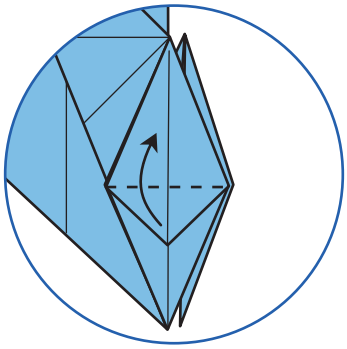
101. Fold **two** flaps to the left.



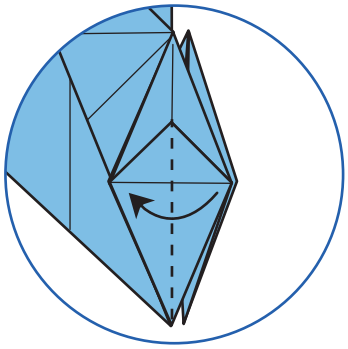
102. Fold one flap down.



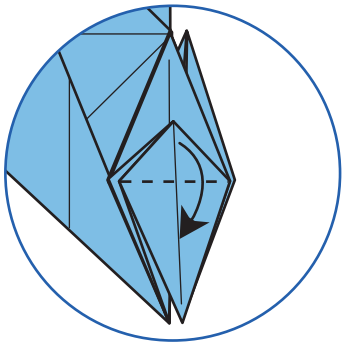
103. Fold one flap to the right.



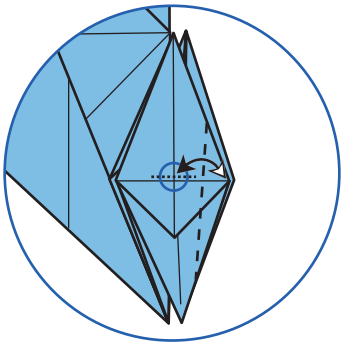
104. Fold the small corner up.



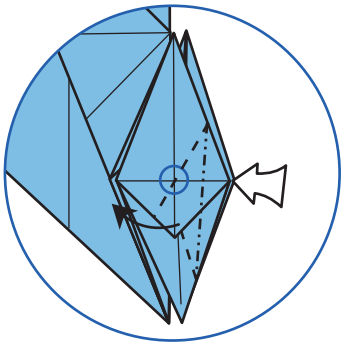
105. Fold one flap to the left.



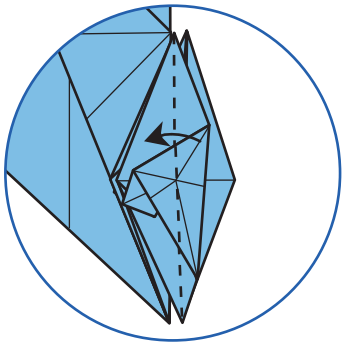
106. Fold the small corner down.



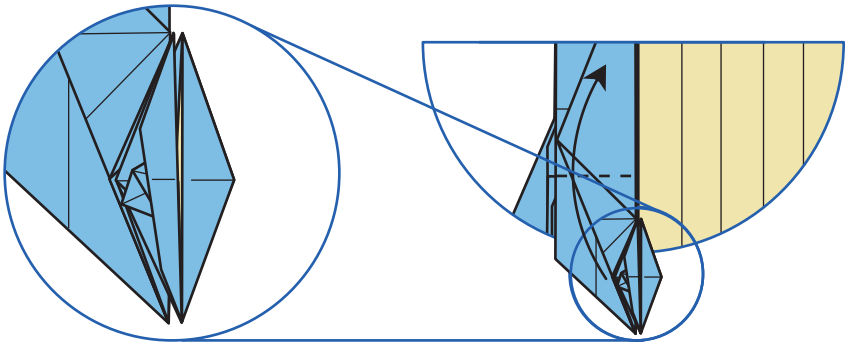
107. Fold the corner on the right to a point just above the centre, then unfold.



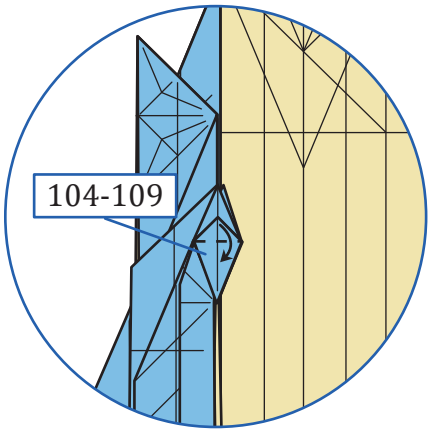
108. Spread-sink the corner using the fold you just made and a new valley which goes through the circled point.



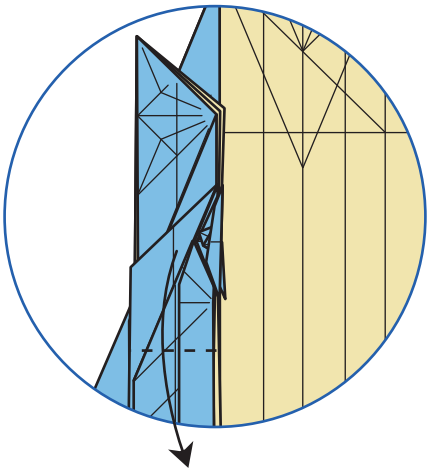
109. Fold one flap to the left.



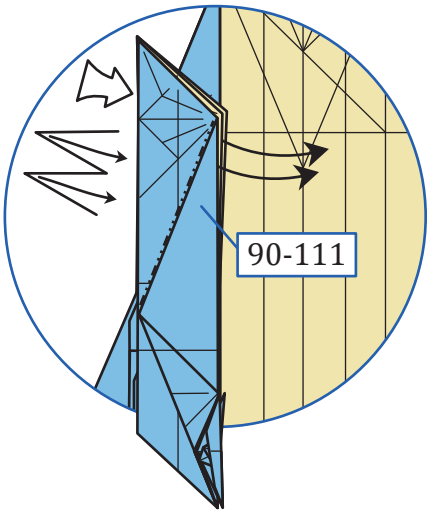
110. Fold the flap up.



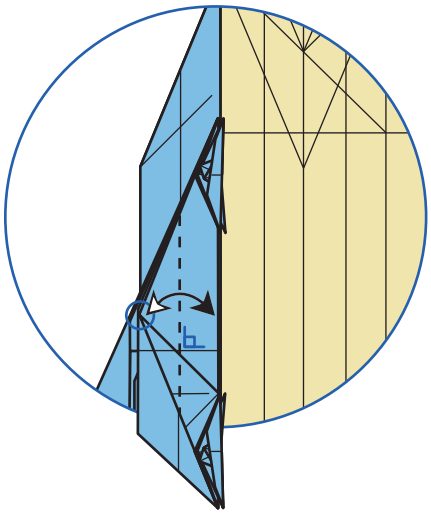
111. Repeat steps 104 to 109, flipping up and down.



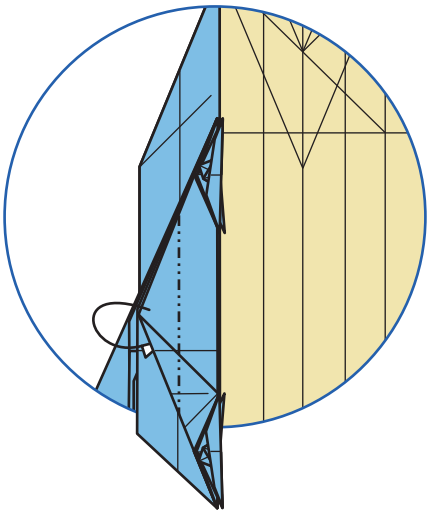
112. Fold the flap down.



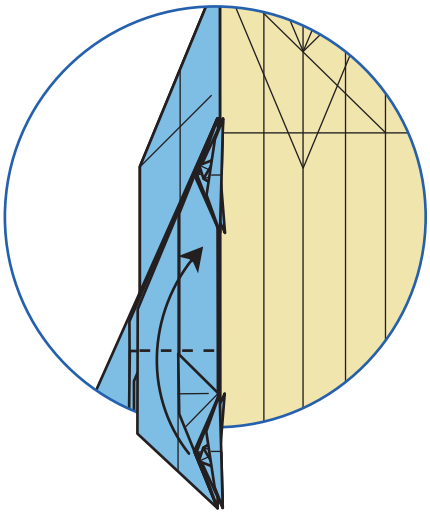
113. Repeat steps 90 to 111 on the next flap.



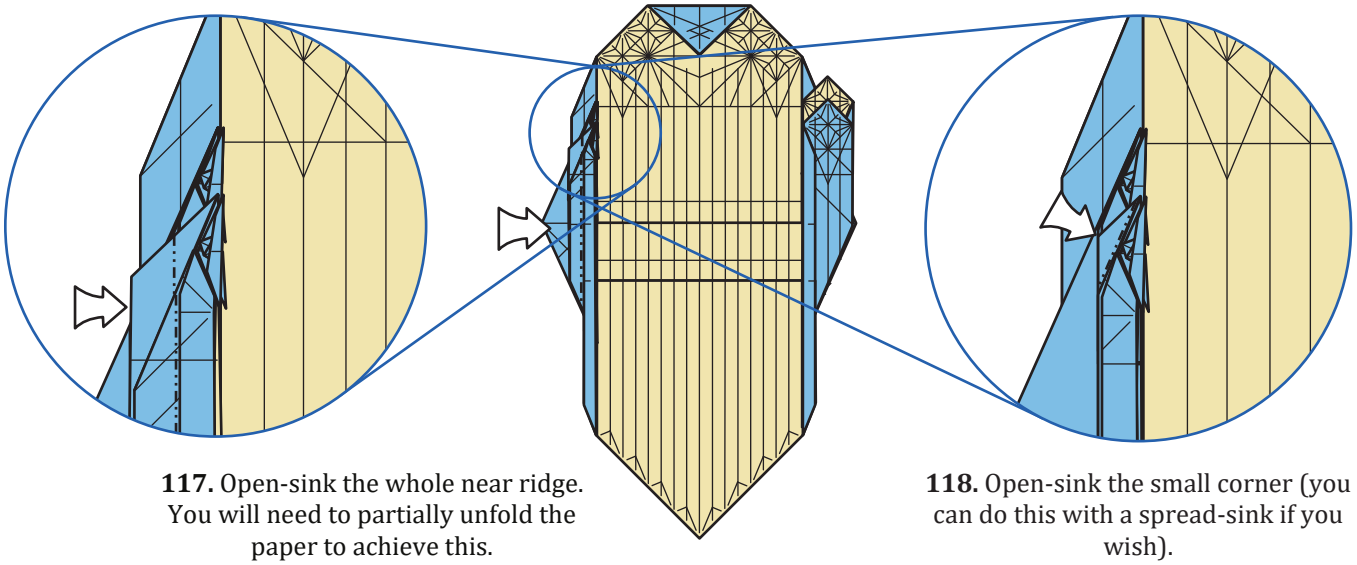
114. Fold the flap in half, and unfold.



115. Mountain-fold using the crease you just made.

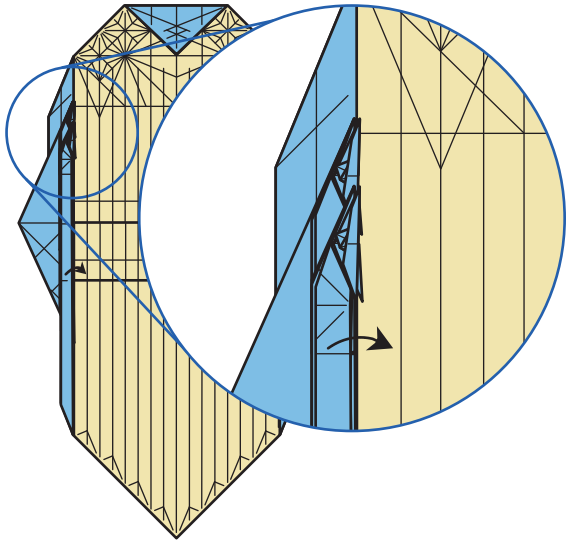


116. Fold the flap up.

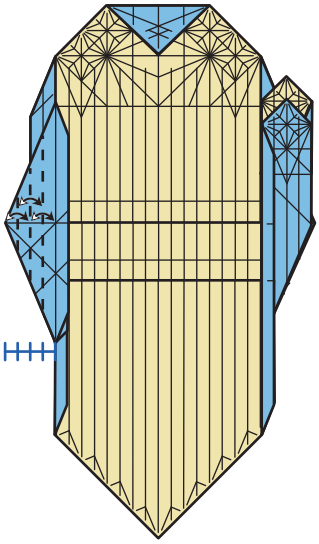


117. Open-sink the whole near ridge. You will need to partially unfold the paper to achieve this.

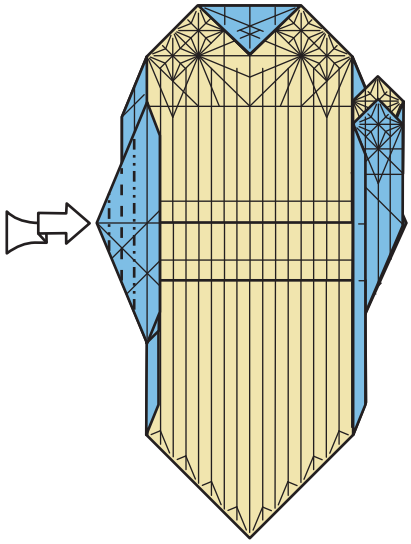
118. Open-sink the small corner (you can do this with a spread-sink if you wish).



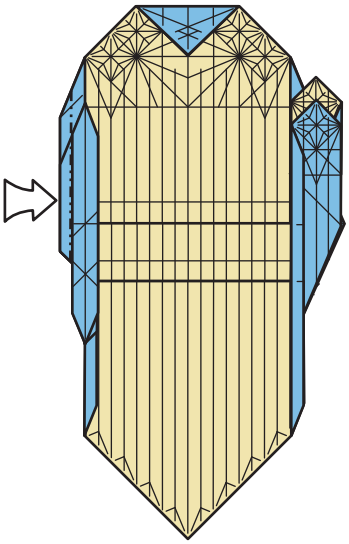
119. Fold one whole set of connected layers to the right.



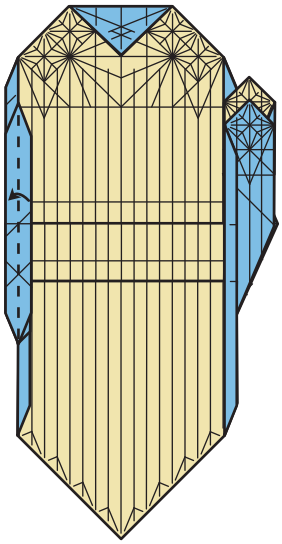
120. Fold and unfold to divide the flap into quarters.



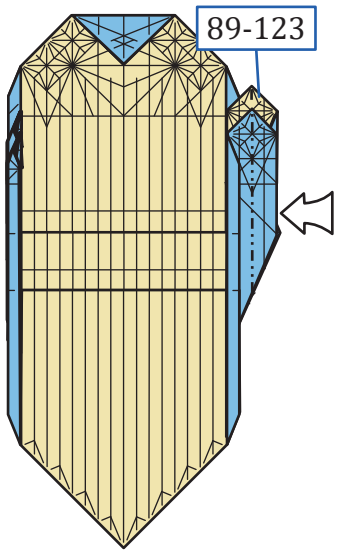
121. Open-sink in and out using the creases you just made.



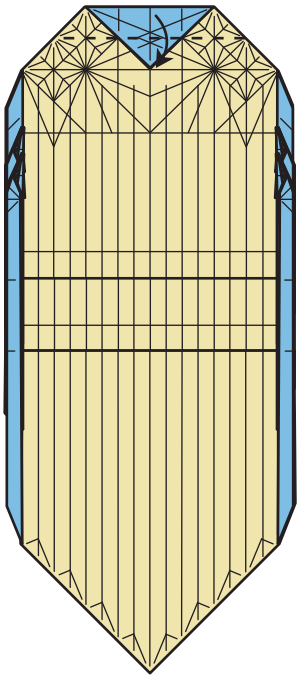
122. Open-sink the final ridge. You will need to partially unfold the paper to achieve this.



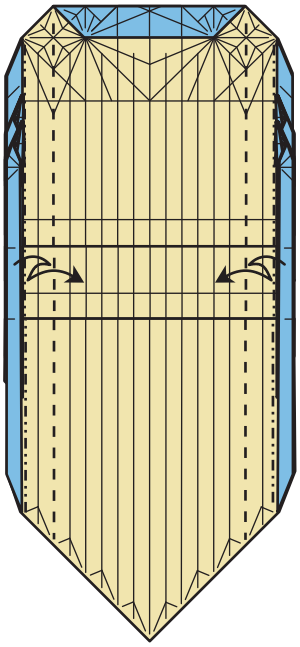
123. Fold the connected layers to the left.



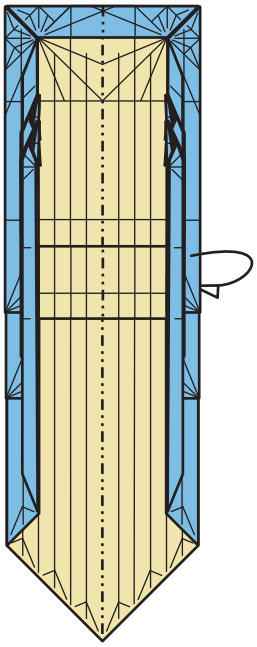
124. Repeat steps 89 to 123 on the right.



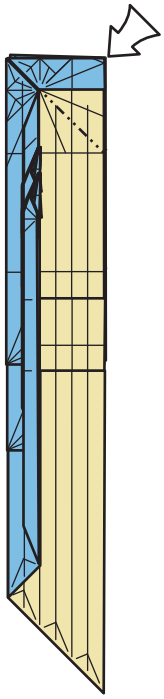
125. Fold the top edge down along an existing crease.



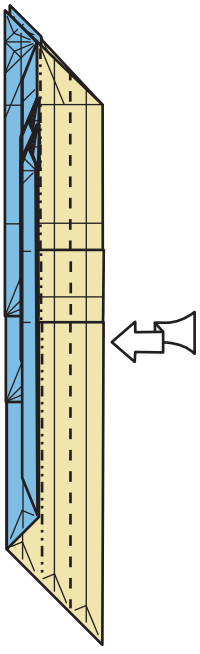
126. Pleat the sides in.



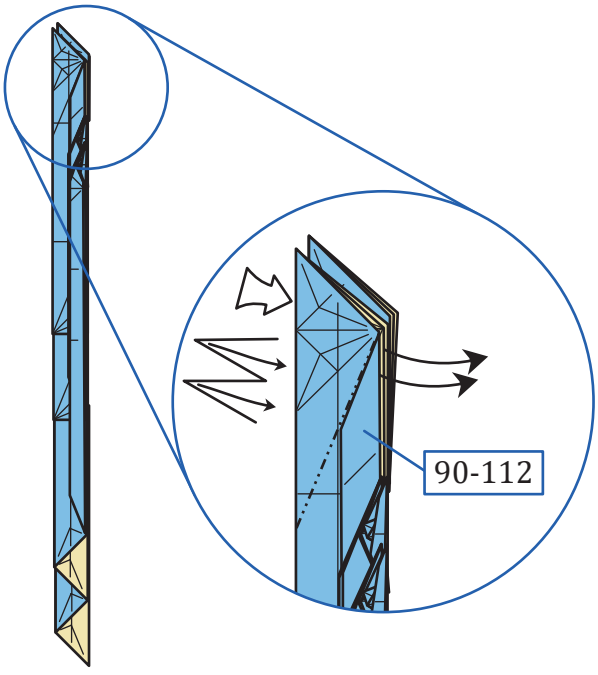
127. Mountain-fold the right half behind the left half.



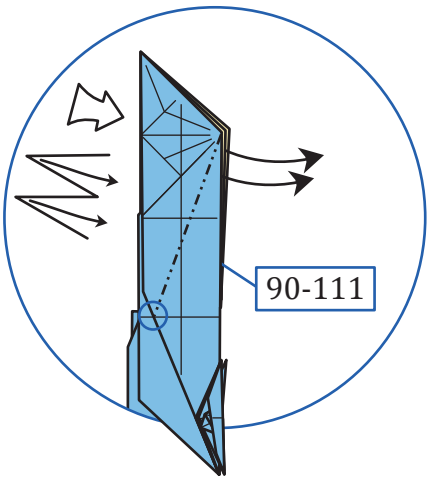
128. Reverse-fold the corner.



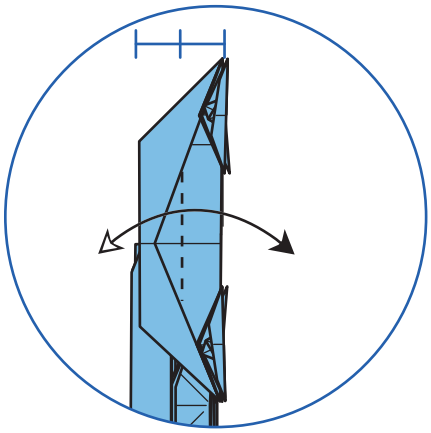
129. Open-sink in and out using mostly existing creases.



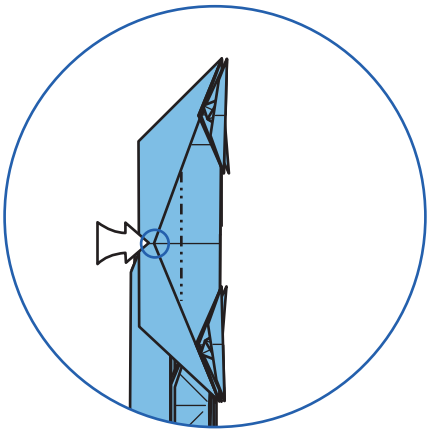
130. Repeat steps 90 to 112 on the near flap.



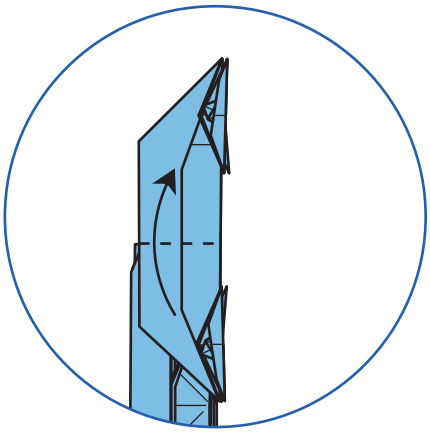
131. Repeat steps 90 to 111. You will have to perform a small closed sink at the circled corner for step 90, and the paper won't quite lie flat for steps 92 to 97.



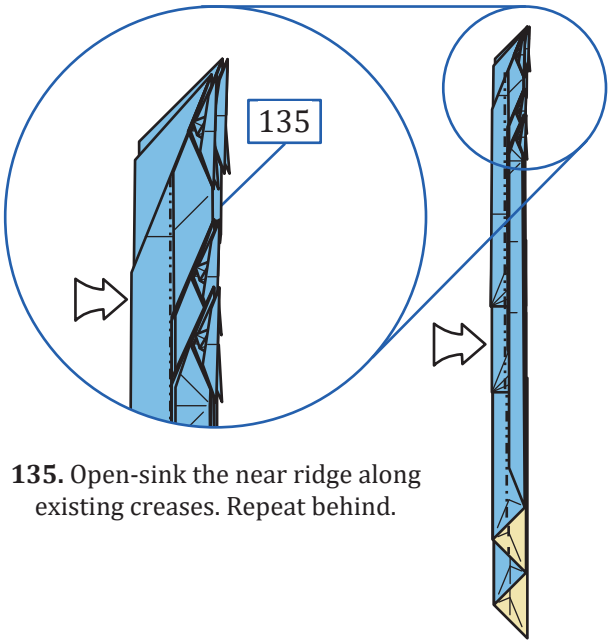
132. Fold a new valley which divides the whole width into two halves.



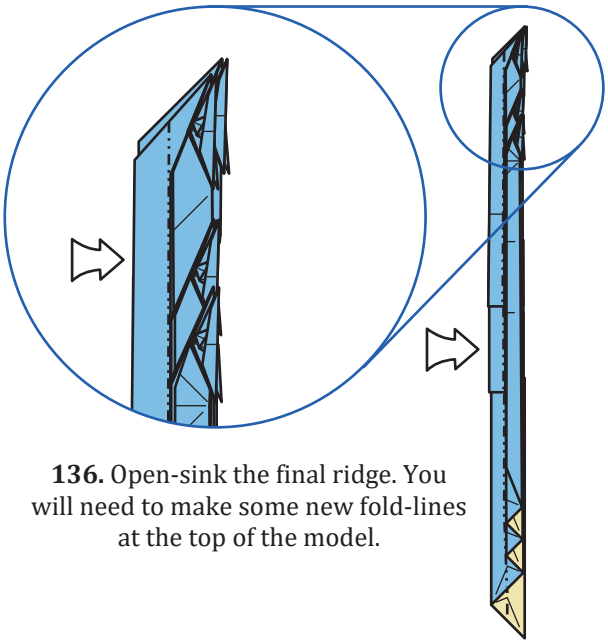
133. Carefully open the paper at the circled corner and open-sink the edge (you can do this with a spread-sink if you wish).



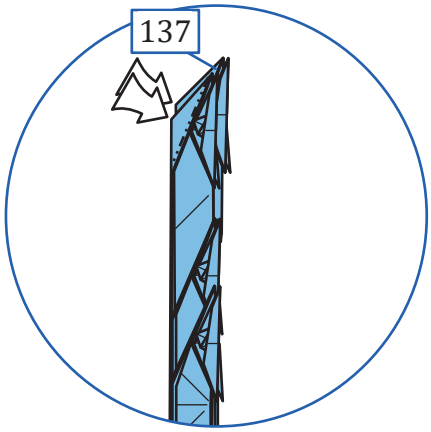
134. Fold one flap up.



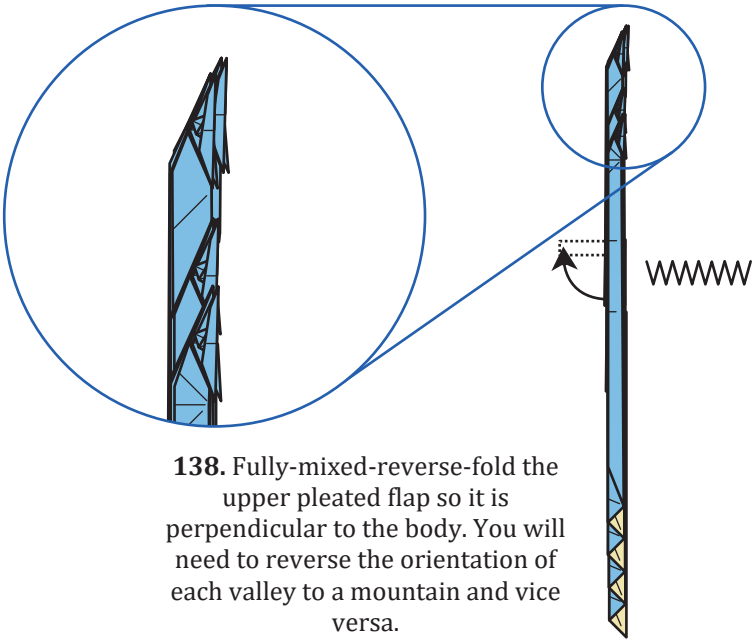
135. Open-sink the near ridge along existing creases. Repeat behind.



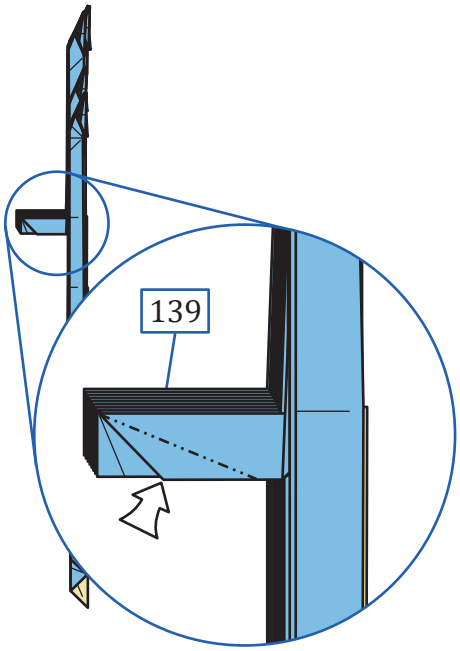
136. Open-sink the final ridge. You will need to make some new fold-lines at the top of the model.



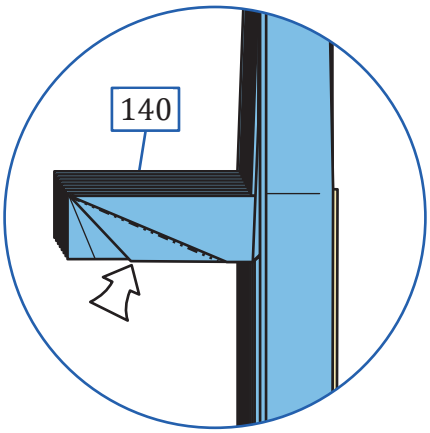
137. Open-sink the small corner (you can do this with a spread-sink if you wish). Repeat behind.



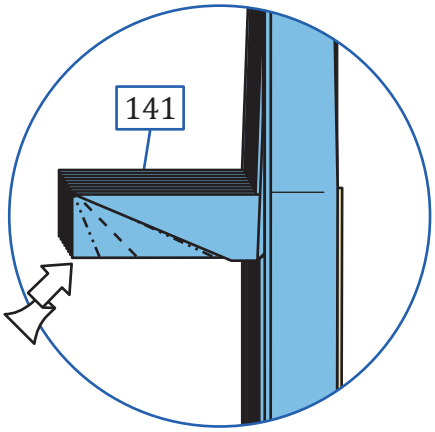
138. Fully-mixed-reverse-fold the upper pleated flap so it is perpendicular to the body. You will need to reverse the orientation of each valley to a mountain and vice versa.



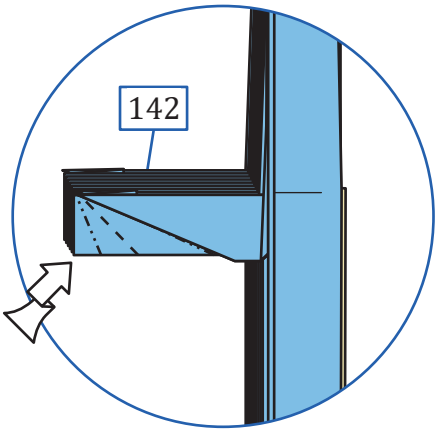
139. Open-sink the corner along an angle bisector. Repeat behind.



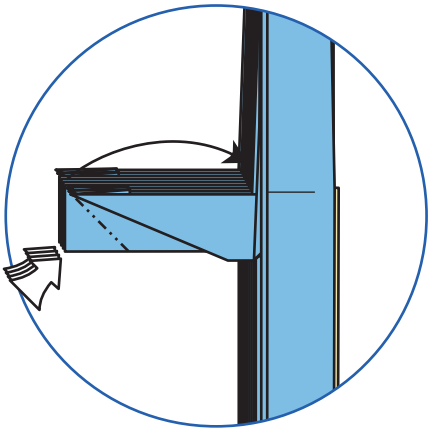
140. Open-sink the next corner along an angle bisector. Repeat behind.



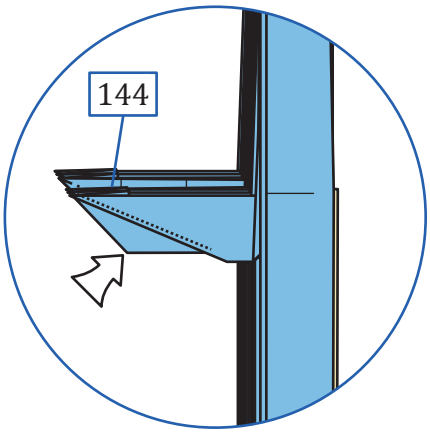
141. Reverse-fold the near corner in and out using existing creases. Repeat behind.



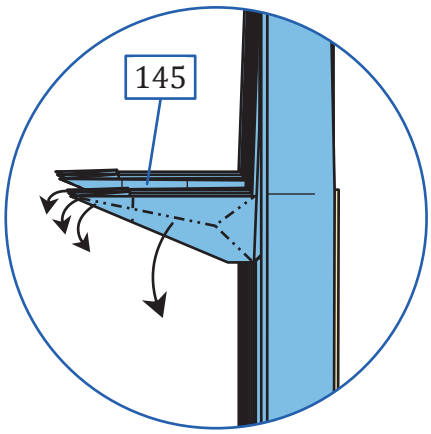
142. Reverse-fold the next corner in and out using existing creases. Repeat behind.



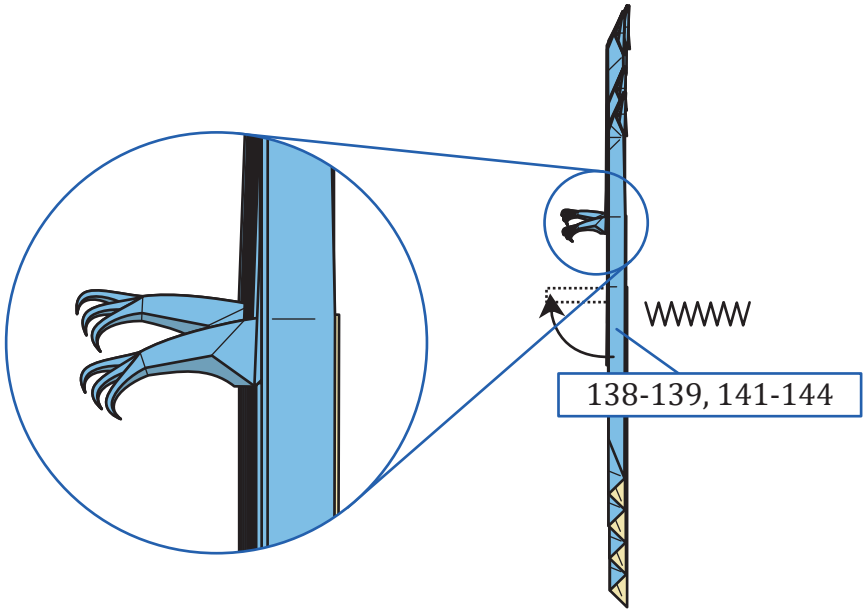
143. Box-stretch the remaining pleats using existing creases to separate the two limbs.



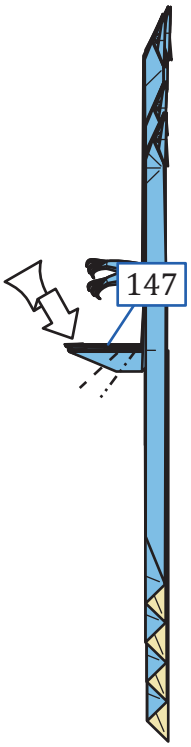
144. Open-sink along angle bisectors. Repeat behind.



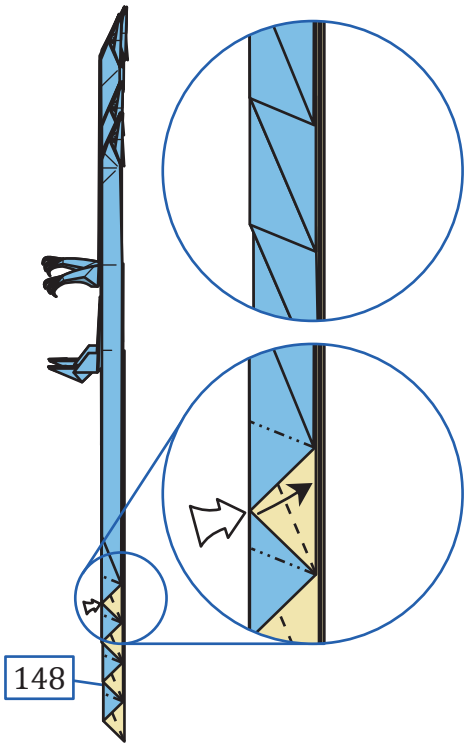
145. Curl the foreleg, and spread the claws. Repeat behind.



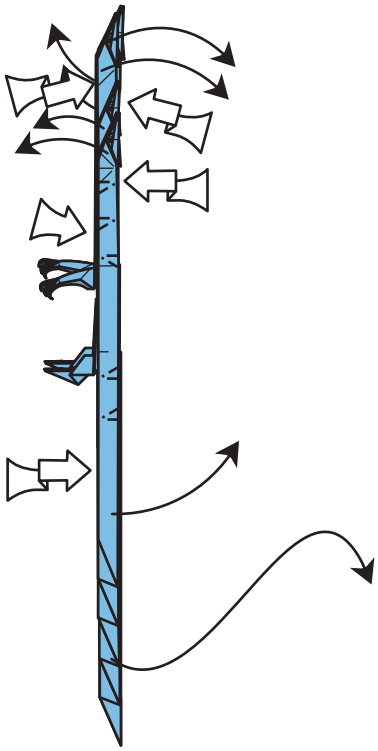
146. Repeat steps 138, 139, and 141 to 144 on the lower flap.



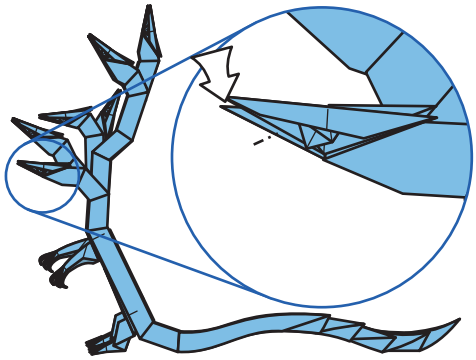
147. Crimp the hind leg down and up again to make feet. Repeat behind.



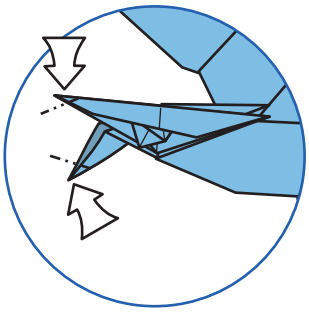
148. Reverse-fold the raw edge in between the four pleats. Repeat behind.



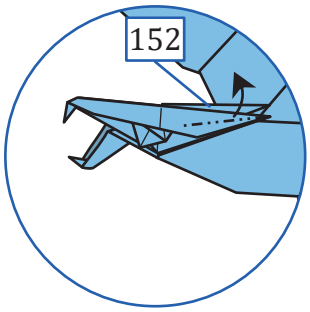
149. Shape the model by crimping or curling the tail and neck segments as you see fit.



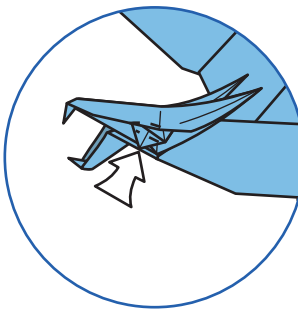
150. Reverse-fold the lower jaw down.



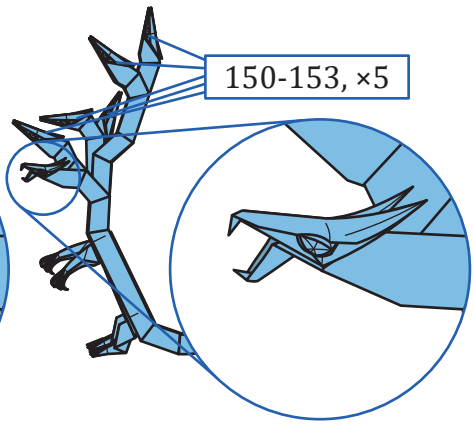
151. Reverse-fold the tips of the jaws to suggest teeth.



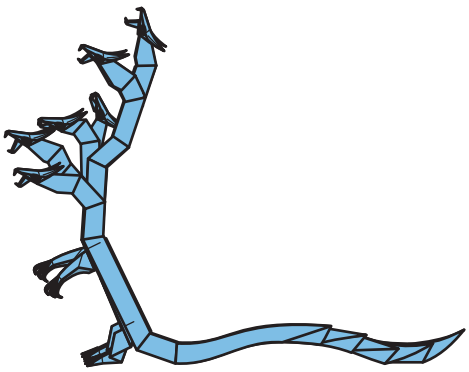
152. Pinch the horn with a mountain fold, and curl it. Repeat behind.



153. Make the eye slightly rounder (if the paper isn't too small!).



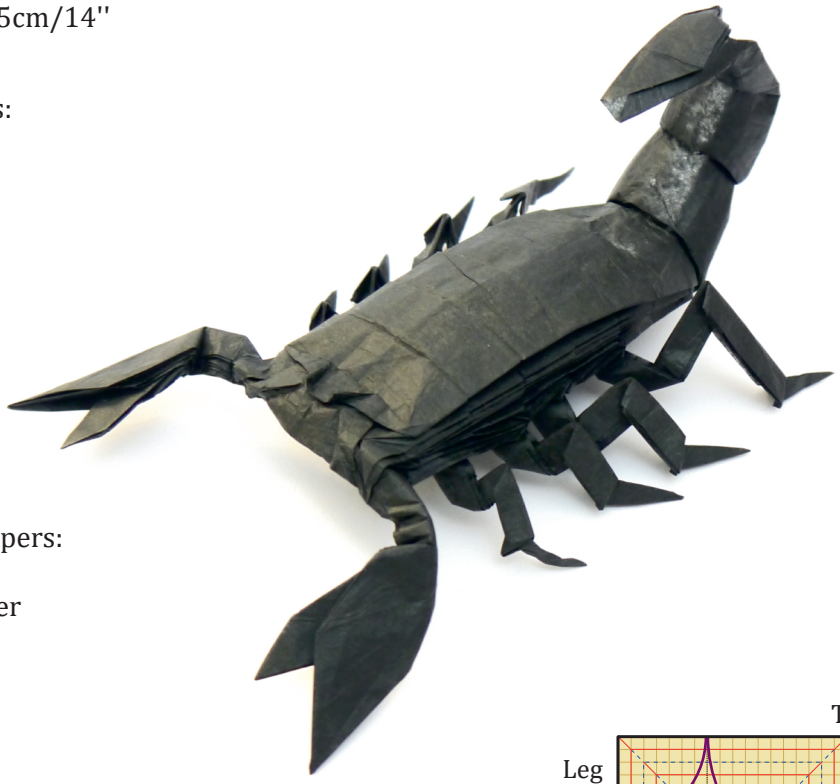
154. Repeat steps 150 to 153 on the other five heads.



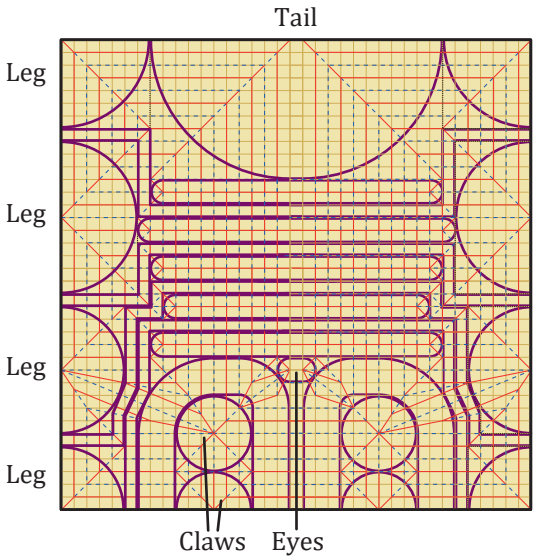
Scorpion

First time: 35cm/14''

Paper preferences:
- Thin
- Shapeable



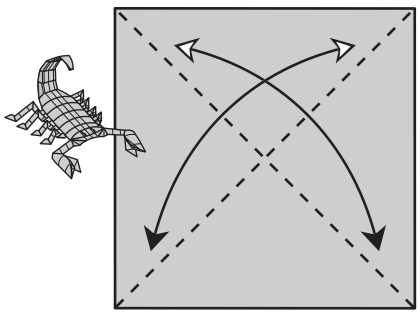
Recommended papers:
- Double tissue
- Foil-backed paper



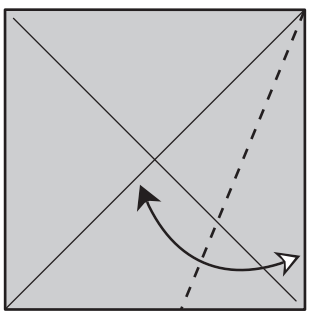
For this model, you need to fold a 37×37 grid, which can be done in several ways. These instructions show a method that only involves folding and has a good compromise between the number of diagrams needed, clarity, and obtaining the most useful valley/mountain orientation of creases. To give credit where it is due, many thanks to Robert Lang for creating *ReferenceFinder*, which found the reference used in step 4. You can find this useful tool on his website, langorigami.com.

If you prefer to use your own sequence, skip steps 2 to 18.

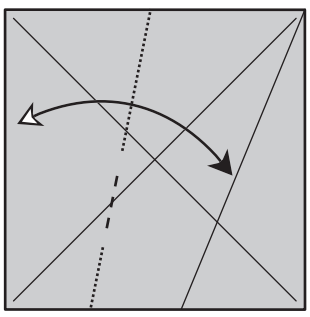
Start body colour side up.



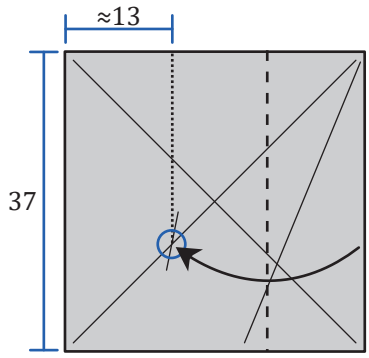
1. Fold and unfold the diagonals.



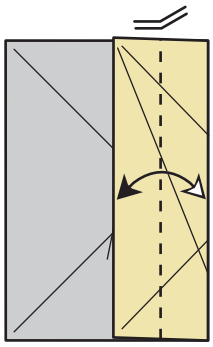
2. Lightly fold the right raw edge to the diagonal and unfold.



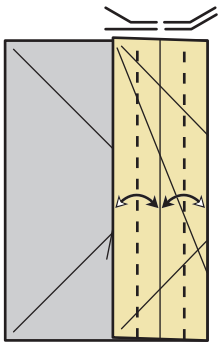
3. Fold the left raw edge to the crease you just made, only marking firmly where shown, then unfold.



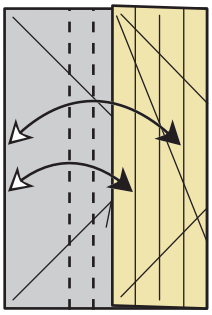
4. Fold the right raw edge to the circled point.



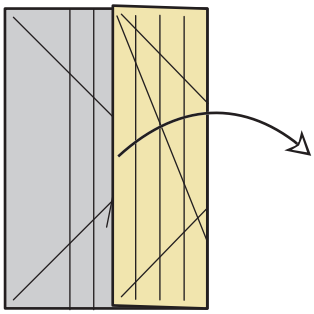
5. Fold and unfold through both layers.



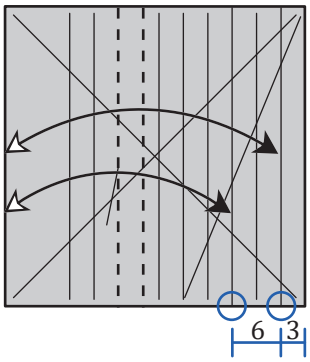
6. Fold and unfold to the crease you just made. Make the right-hand fold through both layers.



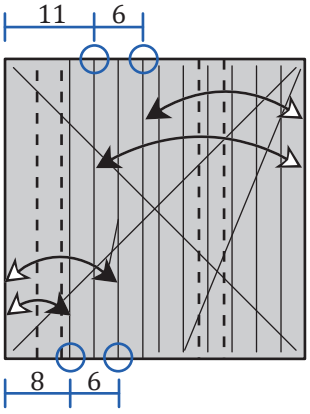
7. Fold and unfold to the creases you just made.



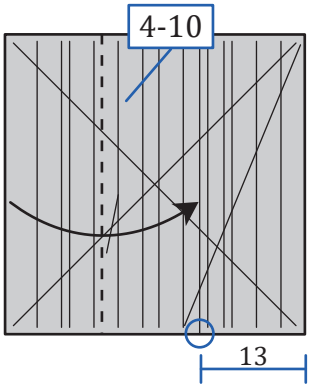
8. Unfold step 4.



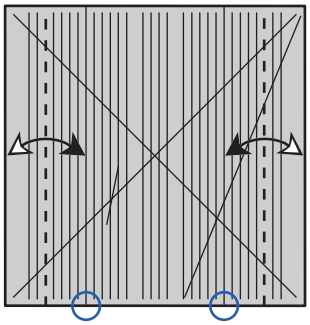
9. Fold and unfold to the creases made in step 6.



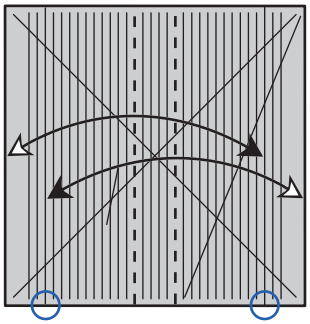
10. Fold and unfold to creases made in steps 7 and 9.



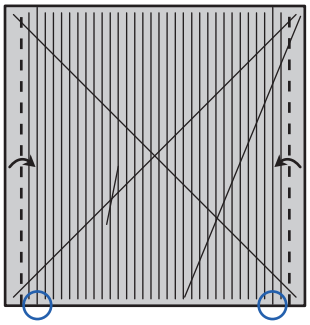
11. Repeat steps 4 to 10, flipping left and right.



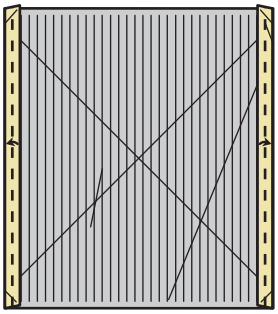
12. Fold and unfold.



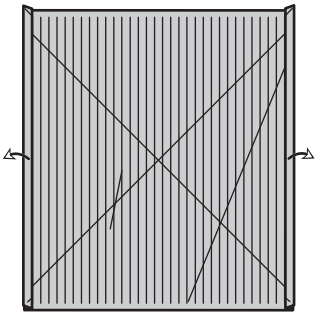
13. Fold and unfold to the creases you just made.



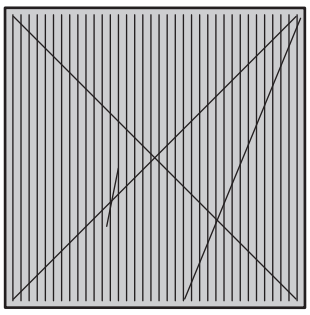
14. Fold the raw edges in.



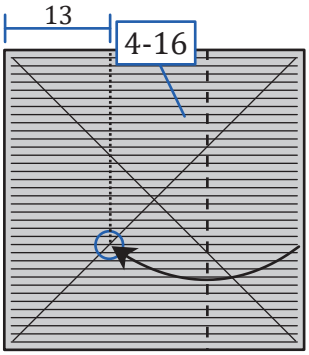
15. Fold the raw edges out.



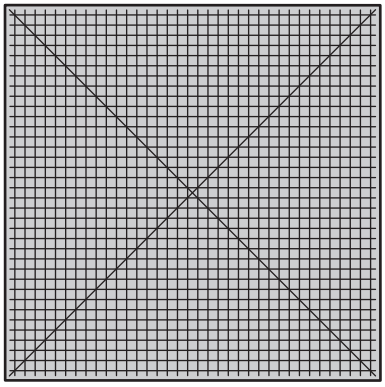
16. Unfold so the paper is flat again.



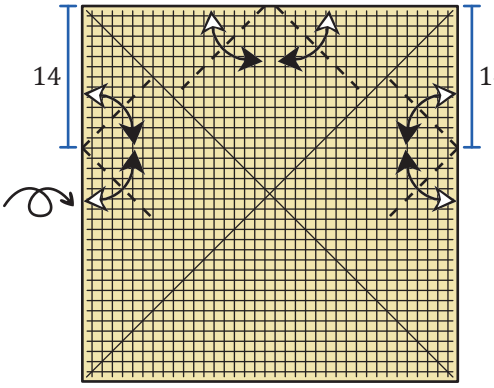
17. Rotate the paper ¼ of a turn clockwise. Some creases will no longer be shown.



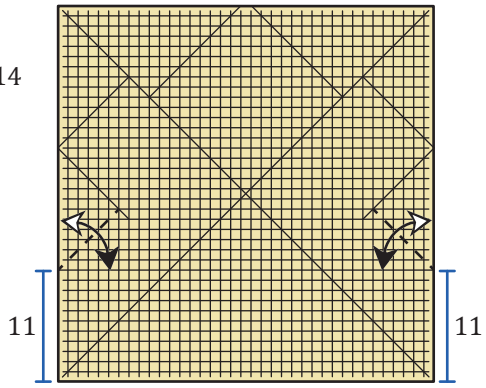
18. Repeat steps 4 to 16.



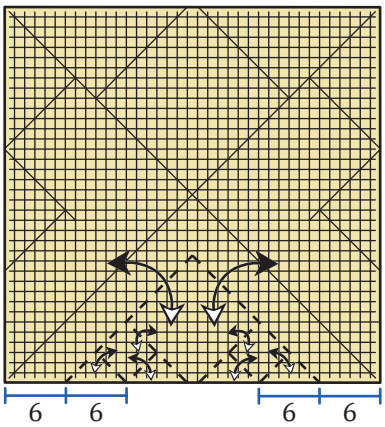
19. Turn the paper over.



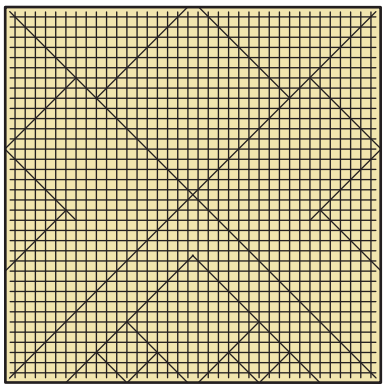
20. Fold and unfold six diagonal lines.



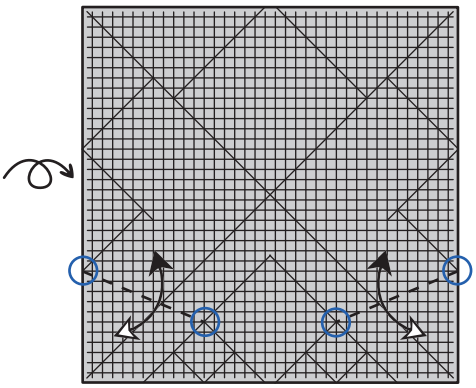
21. Fold and unfold two diagonal lines.



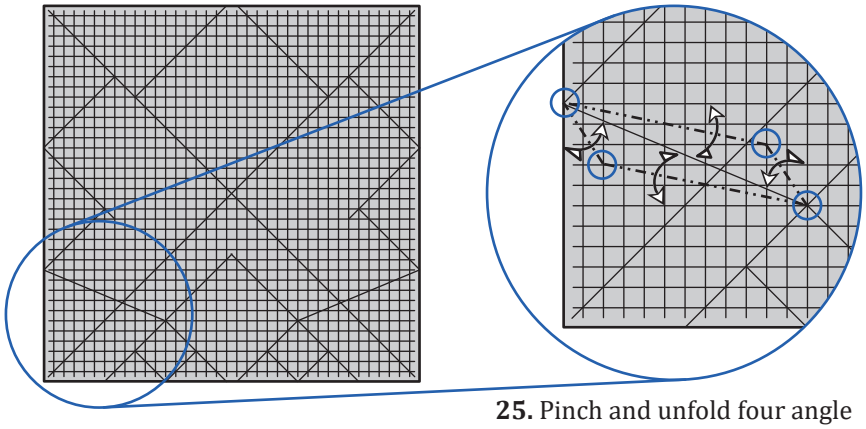
22. Fold and unfold eight diagonal lines.



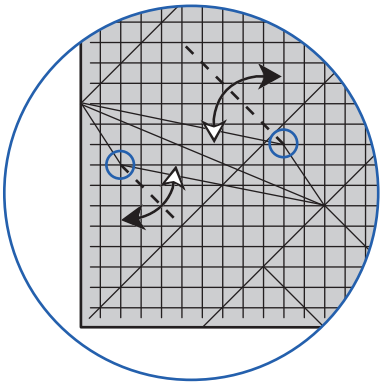
23. Turn the paper over.



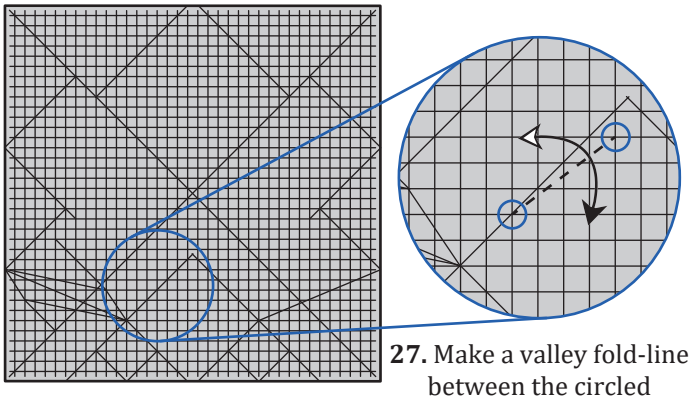
24. Make new valley fold-lines between the circled points.



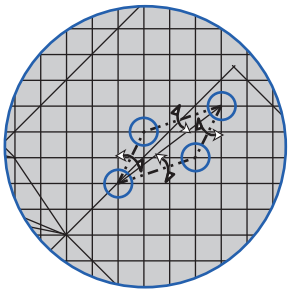
25. Pinch and unfold four angle bisectors as **mountain folds** which connect the circled intersections.



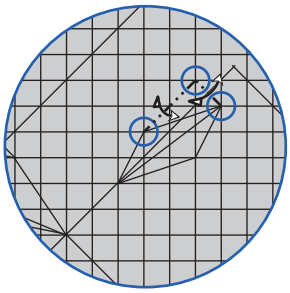
26. Fold and unfold two diagonal lines.



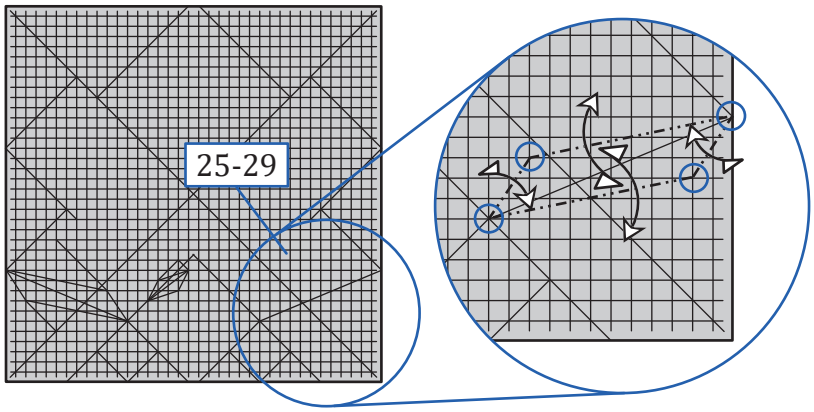
27. Make a valley fold-line between the circled points.



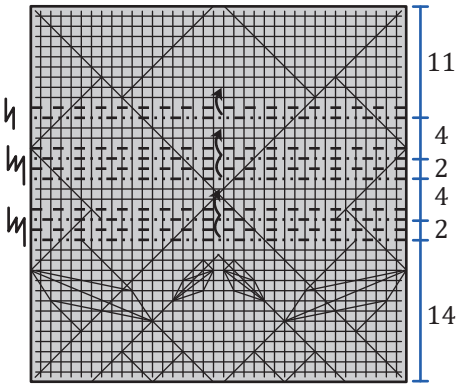
28. Pinch and unfold four angle bisectors as **mountain folds** which connect the circled intersections.



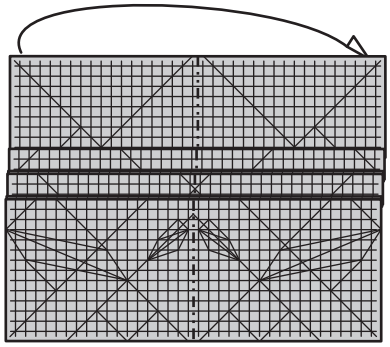
29. Pinch and unfold two diagonal lines as **mountain folds** which connect the circled intersections.



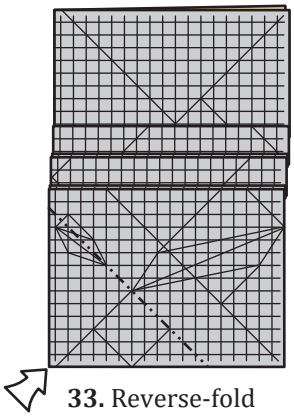
30. Repeat steps 25 to 29 on the right.



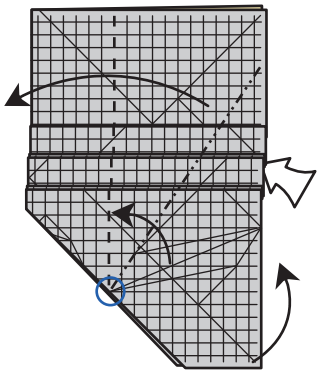
31. Make five pleats at the indicated locations. The vertical distances show the location of the mountain folds.



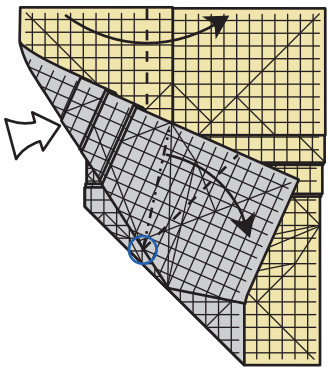
32. Gently bend the left half behind the right half. Resist the temptation to flatten the paper; only fold this firmly in future steps as and when you need to.



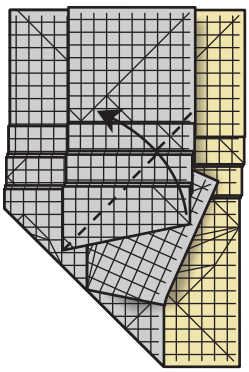
33. Reverse-fold using existing creases.



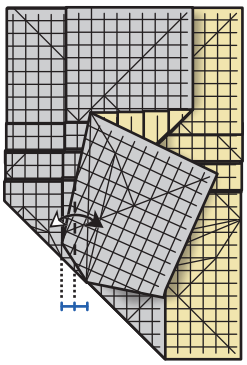
34. Swivel-fold the near layer, pivoting about the circled point so the crease made in step 24 becomes vertical. Don't flatten firmly except where there are existing creases.



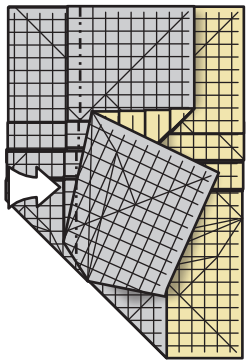
35. Swivel-fold the near layer, using a mountain fold made in step 25. Don't flatten firmly except where there are existing creases.



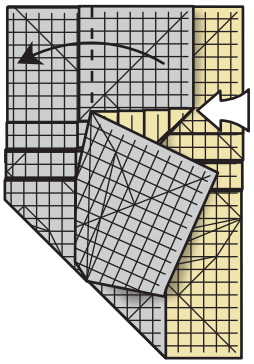
36. Fold the flap up using an existing crease in the nearest layer.



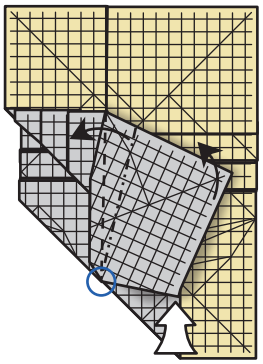
37. Fold and unfold a vertical line in the near layers.



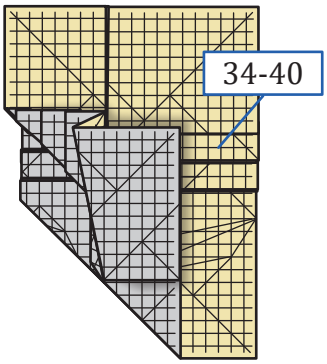
38. Open-sink the thin edge.



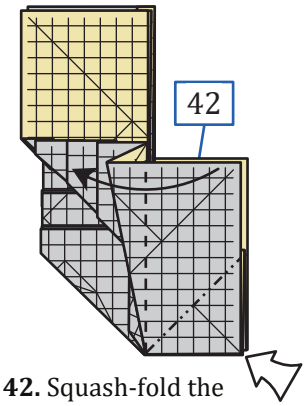
39. Reverse-fold to the left.



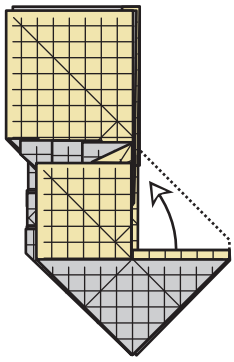
40. Swivel-fold the near layer, so that the near layer is no longer twisted.



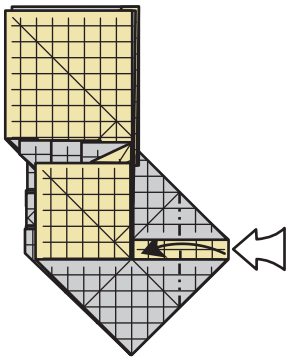
41. Repeat steps 34 to 40 behind.



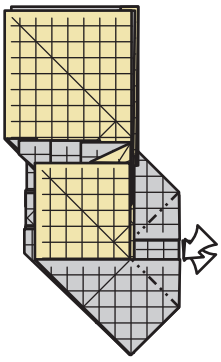
42. Squash-fold the corner. Repeat behind.



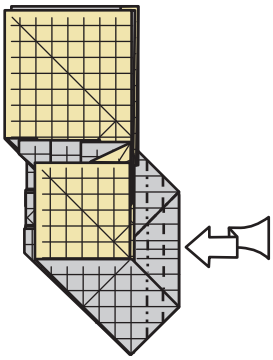
43. Fold the flap on the back upwards.



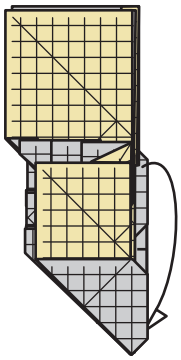
44. Reverse-fold the raw edge into the centre.



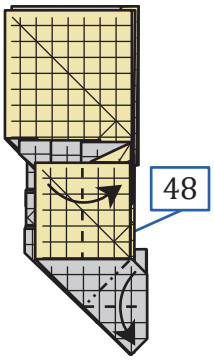
45. Reverse-fold the two corners.



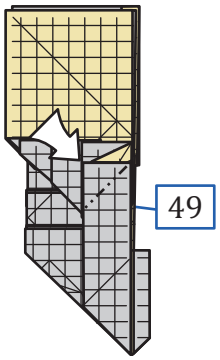
46. Open-sink the edge in and out.



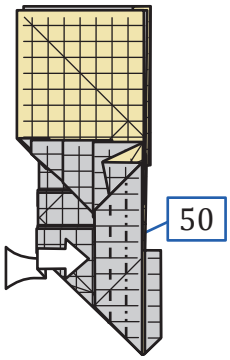
47. Fold the flap on the back down.



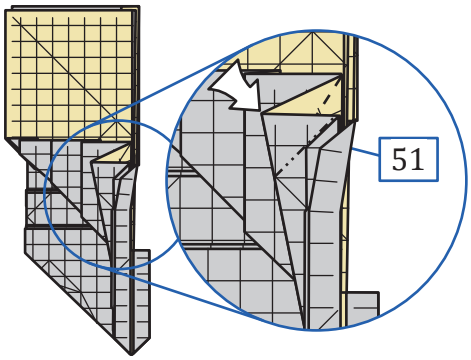
48. Swivel-fold using existing creases. Repeat behind.



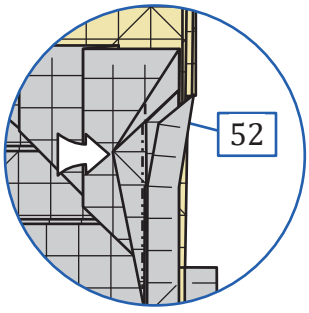
49. Reverse-fold the corner. Repeat behind.



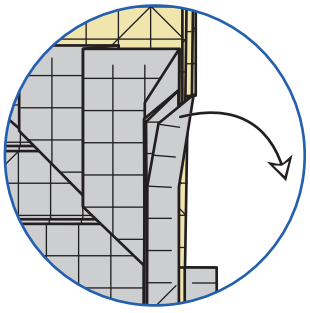
50. Open-sink in and out. Repeat behind.



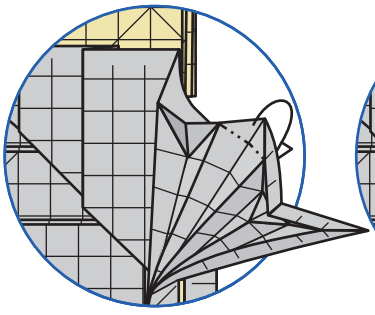
51. Reverse-fold. Repeat behind.



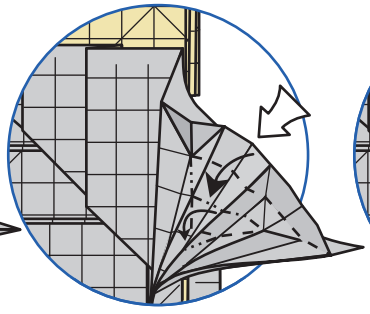
52. Open-sink. Repeat behind.



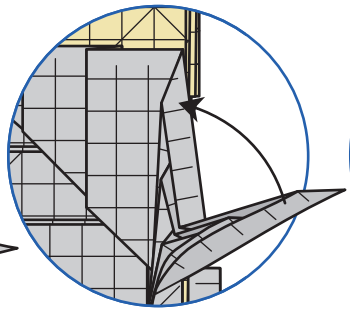
53. Pull the corners to the right. The paper won't lie flat until after step 56.



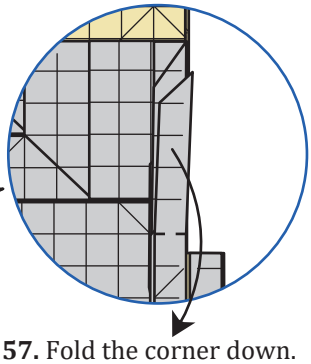
54. Mountain-fold the corner behind.



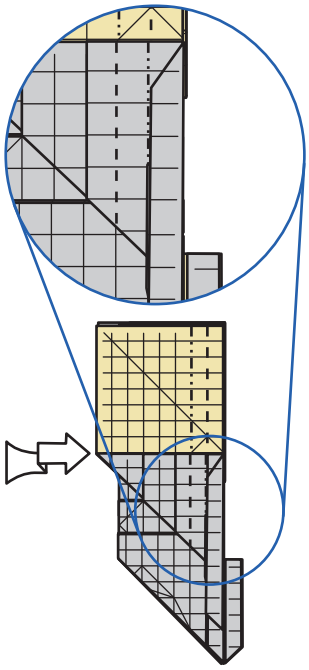
55. Continue to box-stretch using existing creases.



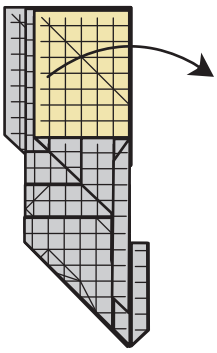
56. Flatten the paper.



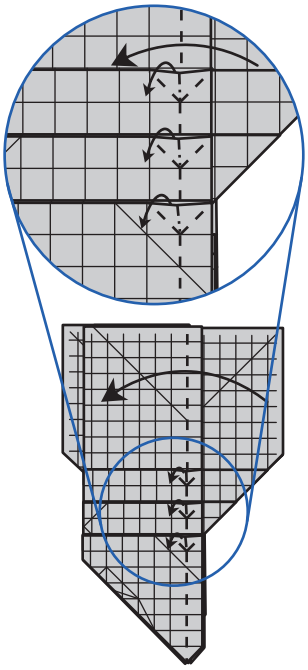
57. Fold the corner down.



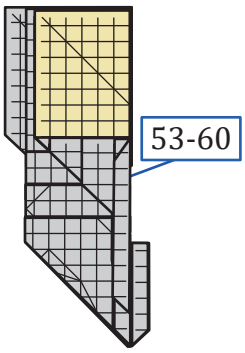
58. Reverse-fold in and out.



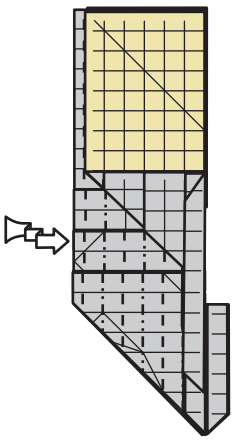
59. Fold the whole connected flap to the right.



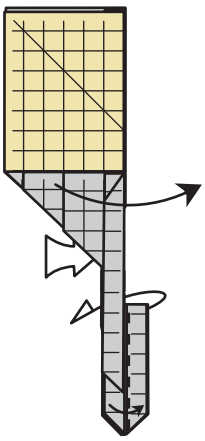
60. Fold the flap back to the left, folding three near edges down.



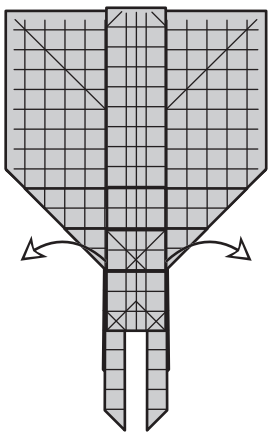
61. Repeat steps 53 to 60 behind.



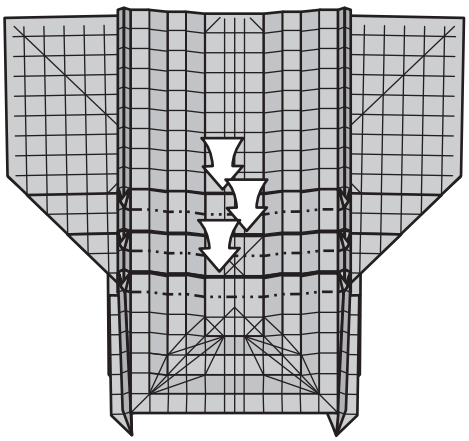
62. Open-sink in and out.



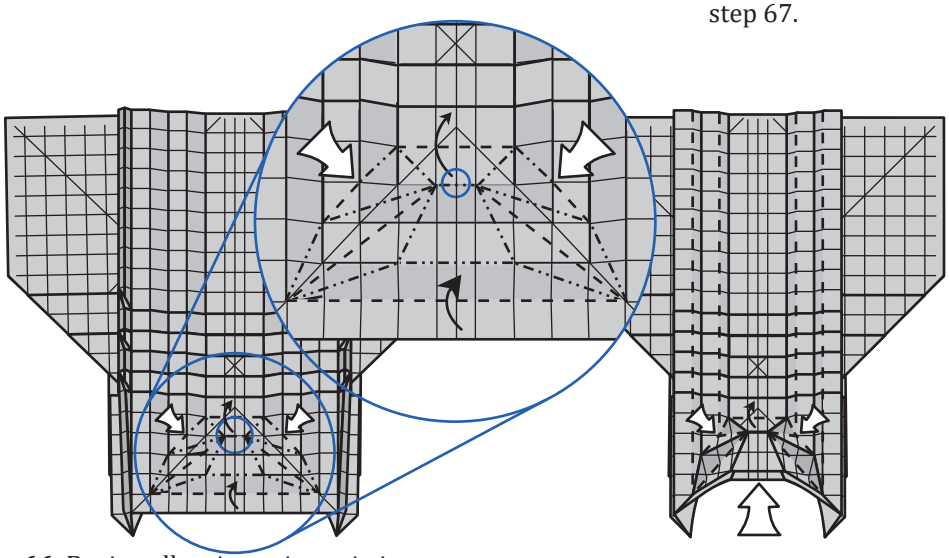
63. Open and spread the central column of squares so the paper is symmetrical and lies flat.



64. Pull the sides apart gently and spread the central pleats. The paper won't lie flat until after step 67.

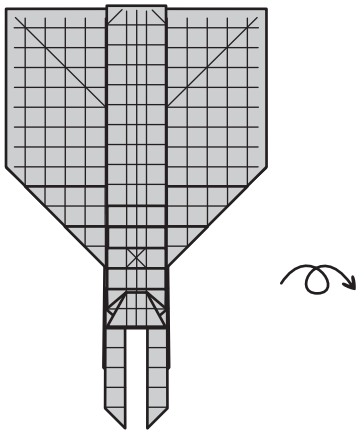


65. Closed-sink three ridges between the folds from step 60 on each side.

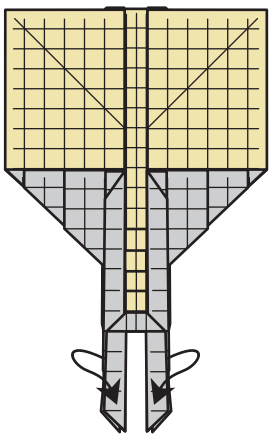


66. Begin collapsing using existing creases to bring the circled ridge upwards.

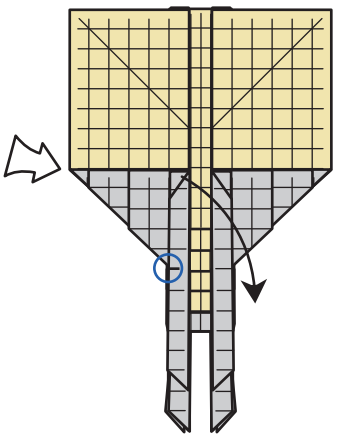
67. Continue collapsing in order to flatten the paper.



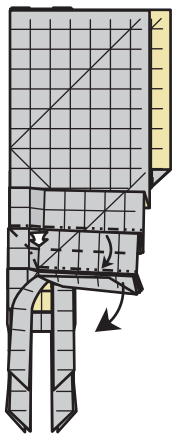
68. Turn the paper over.



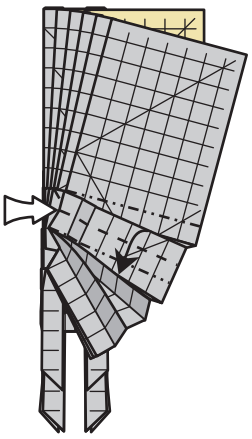
69. If the near raw corners are not at the front, rearrange the layers to bring them to the front.



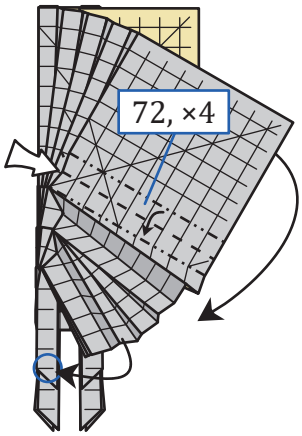
70. Bring the edge down, pivoting about the circled corner, and spread the paper to the right. The paper won't lie flat until after step 73.



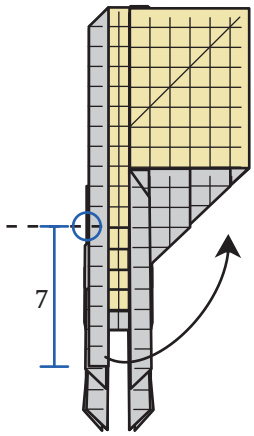
71. Straighten the upper mountain fold, and pleat where shown, bringing the horizontal fold-lines down so that they become vertical.



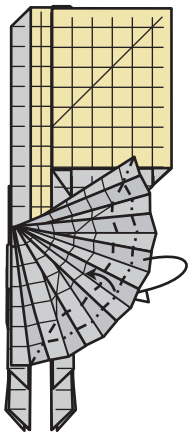
72. Continue to box-stretch, pleating the next pair of edges together.



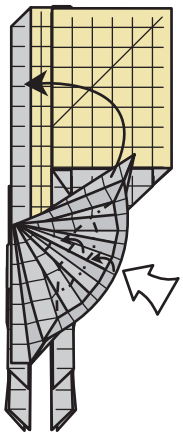
73. Repeat step 72 four more times, box-stretching until the paper is flat. The diagonal crease going to the top of the paper (made in step 20) can be used as a guide: it will be folded, and alternates between mountains and valleys. The raw edges at the end of the pleats will be on top of each other, at the circled point.



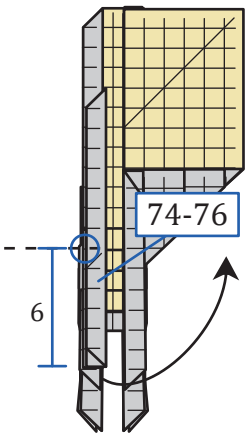
74. Lift the raw corner, spreading the nearest 7 pleats (14 layers) evenly. The paper won't lie flat until after step 76.



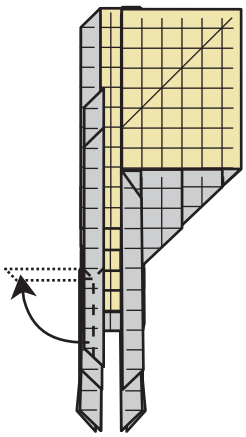
75. Box-stretch the outermost pleat using existing creases.



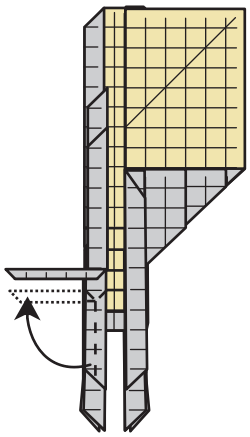
76. Box-stretch the remaining pleats until you can flatten the corner upwards.



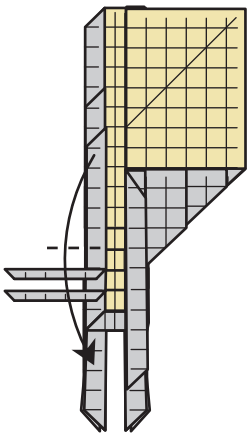
77. Repeat steps 74 to 76 on the next 6 pleats. Pull the flap up so it is 6 squares long before flattening.



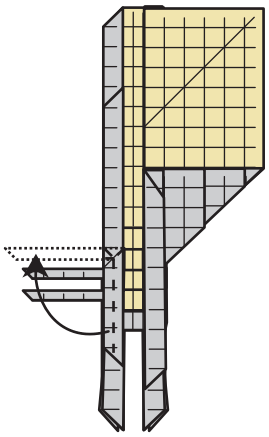
78. Fold the near flap in half with a rabbit ear to the left.



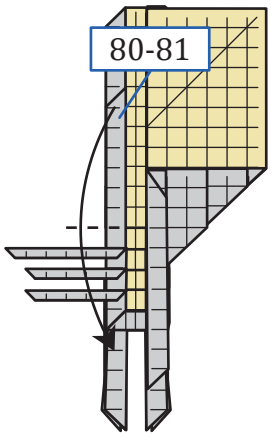
79. Rabbit-ear the next flap to the left.



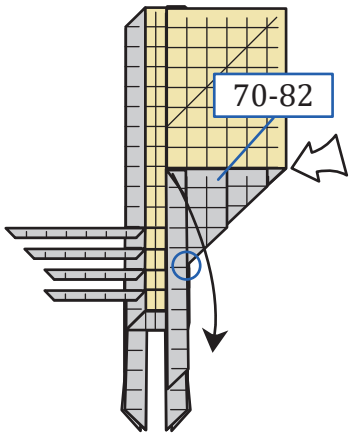
80. Fold one flap down, as shown.



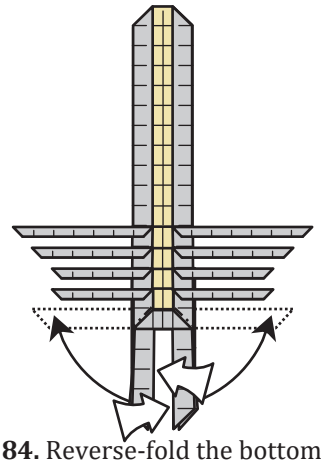
81. Rabbit-ear the flap to the left.



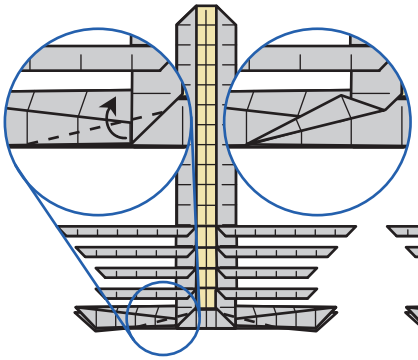
82. Repeat steps 80 and 81 on the next flap.



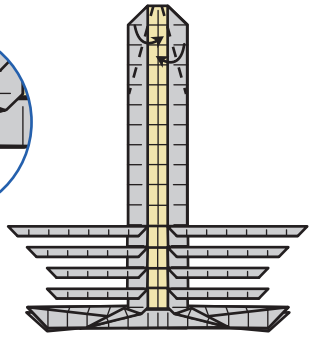
83. Repeat steps 70 to 82 on the right.



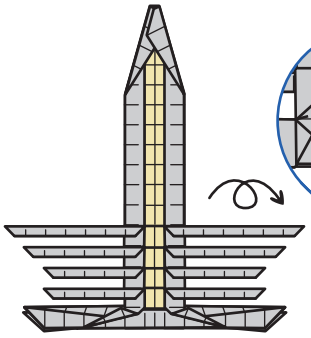
84. Reverse-fold the bottom flaps outwards. The mountain-fold along the spine is just after the very narrow central flap.



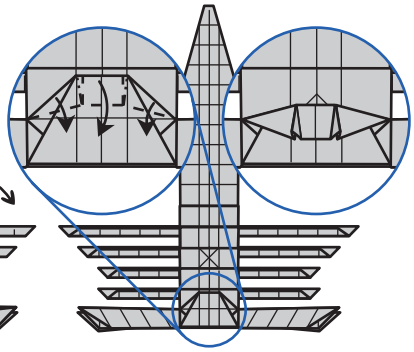
85. Fold two obtuse angles up on each side.



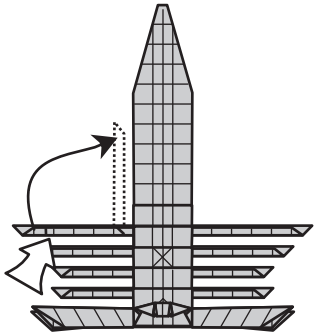
86. Fold the corners at the top in, so that they overlap.



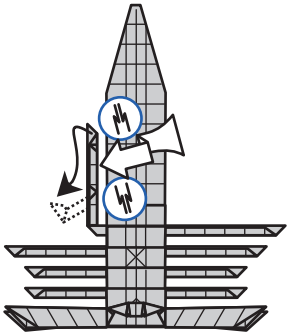
87. Turn the paper over.



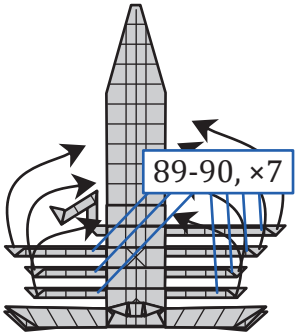
88. Perform two small rabbit ears on the same flap to suggest eyes.



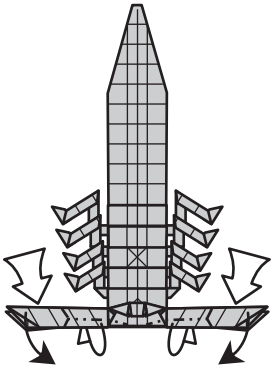
89. Reverse-fold the leg.



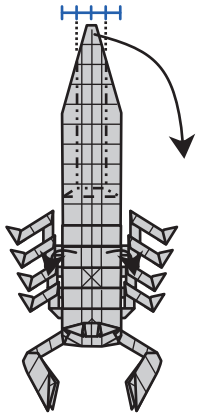
90. Crimp the leg twice to make a knee and foot.



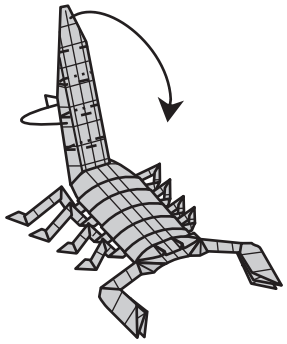
91. Repeat steps 89 and 90 on the other 7 legs.



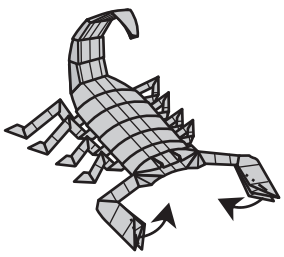
92. Crimp the claws forwards, while narrowing the inner parts of the flaps with mountain folds.



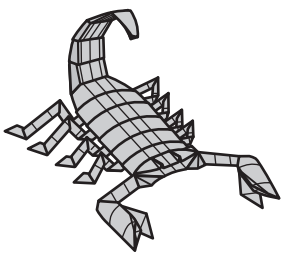
93. Curl the body slightly and crimp the tail so that it becomes vertical.



94. Curl the tail with more crimps.



95. Open and shape the claws.



SCORPION

BEHIND THE DESIGN

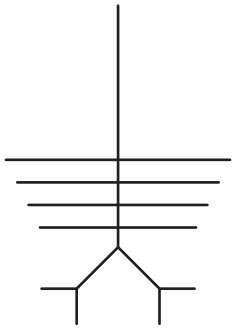
One of the things I enjoy most about origami design is that it is non-competitive. There is no way to meaningfully rank all designs in order of how good they are, because there are so many subjective factors. Nonetheless, designers sometimes follow trends and attempt to one-up each other by putting their own slant on a subject. Typically, this leads to designs becoming more complicated over time because the most obvious way to develop a subject is to add more details.

One popular ongoing trend is to design a scorpion that has increasing leg lengths towards the back of the body. It's a natural subject for designers to congregate around because the easiest way to make multiple neighbouring flaps is to repeat the same crease pattern for each flap, which results in them all being the same length. Therefore, the designer has to think a little bit harder than usual for these legs. Not to mention, there are a number of details the designer can choose to add and a variety of scorpion species to depict. This scorpion has me throwing my hat into the ring with my preferred balance between including lots of features, efficiency, and folding difficulty.

At nearly 100 steps, it may feel like a long sequence, but this compares favourably with other similar scorpion designs. The step count is kept down by continually prioritising simplicity. The next few pages will show this by looking at the three main aspects of this design: the challenge of varying leg length, how to include pleats on the back, and the inclusion of Pythagorean stretches.

Varying leg lengths

As usual, we can make good initial progress by considering a tree for a scorpion that includes the minimum number of features we'd be happy with.

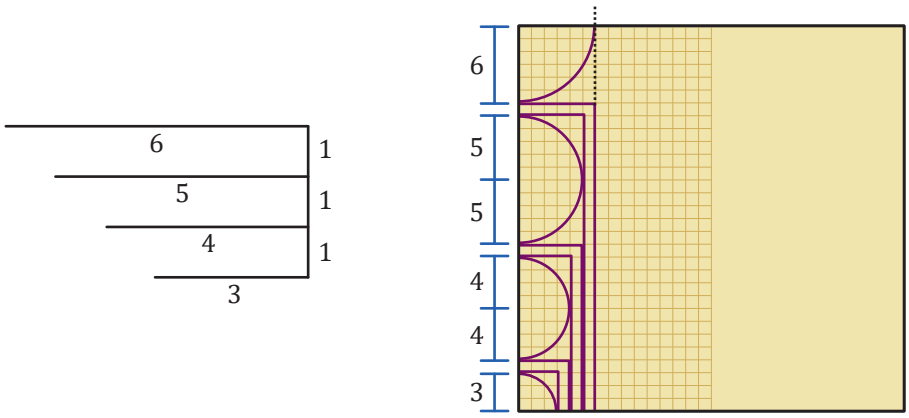


An initial tree for a scorpion. None of the relative lengths are finalised at this stage.

A scorpion's legs are much thinner than the tail or claws, so we should make it a priority to fold the legs from the edges of the paper rather than the middle (scorpions aren't known for their colours, so we don't have to allot any of the paper at the raw edges for anything else).

For simplicity, we should make the gaps between the legs all the same distance. These gaps will correspond to the width of rivers in our final crease pattern and are the shortest distances between any nodes on the tree. The easiest way to make multiple rivers of the same length is to use box pleating (which will also help us if we choose to make pleats for the hard segments (tergites) on the upper part of the scorpion's abdomen). This means we want all lengths on the tree to be integer multiples of this unit length.

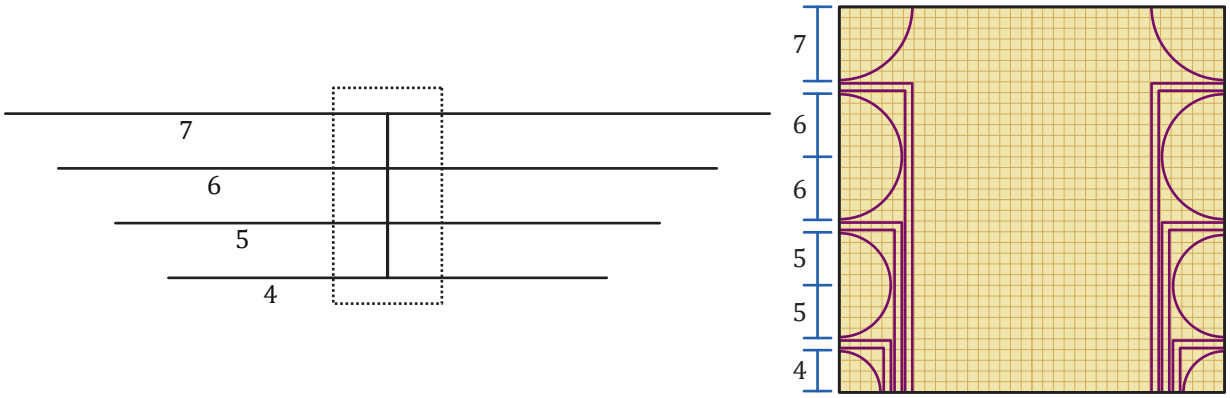
As a consequence, the difference between adjacent leg lengths must also be a multiple of this unit length. Therefore, to keep the difference as small as possible, the legs will end up having consecutive integer lengths. Relative to the unit length, the closest integer approximations for the leg lengths on the initial tree are 3, 4, 5, and 6. We can find a convenient circle/river arrangement for these flaps with a little bit of experimentation.



Left: A tree for four legs (with lengths 3, 4, 5, and 6).
Right: A circle/river arrangement for the tree. This arrangement creates a vertical divide between the legs and the rest of the paper which is characteristic of easy-to-fold origami.

In fact, this sort of staggered arrangement is *only* possible when the flap lengths vary, because the distances between the flap tips (the centres of the circles) are all even. If instead the flaps were all the same length but we still had a one-unit gap between legs, the resulting odd distances between flap tips wouldn't allow the mountains and valleys to alternate, which would prevent the crease pattern from collapsing without extra work (e.g. doubling the grid number to make each distance a multiple of two). We'll discuss this topic of distances being odd or even – a property called the **parity** of a number – in more detail in a few pages.

In the above example, the shortest leg is only 3 units long, which will really be too short. Observe that the tree above doesn't take into account the width of the abdomen, which will protrude out over the legs and make the leg flaps appear shorter than these numbers in practice. If we decide now that we'll end up using the smallest possible width for the body, the overlap will be 1 unit, so let's add 1 to the leg lengths above.

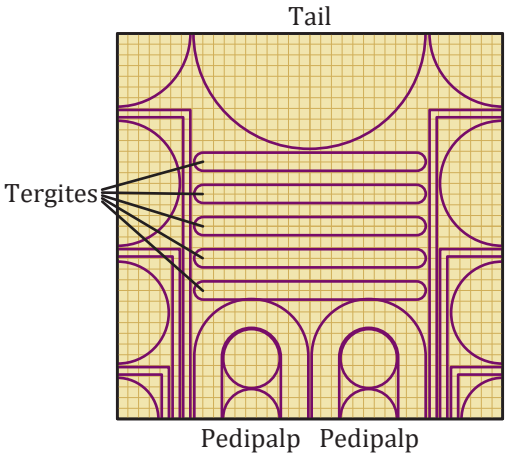


Left: A tree for four pairs of legs (lengths 4, 5, 6, 7), to account for the region of the legs hidden under the abdomen.
Right: A circle/river arrangement for the tree. This arrangement requires a 36×36 grid.

Adding pleats

This leaves a region in the middle that looks suitable for a tail at the top and the two claw arms at the bottom, including the pincers (together called the pedipalp). We'll add circles and rivers for these too, which thankfully seem to be about the right size for these body parts. This leaves a large unfilled region in the centre of the paper, which is along the scorpion's back. We don't have to waste this paper because we can use it for several pleats to depict tergites. In a circle/river arrangement, pleats can be represented by wide flaps which are only one unit long. These can be used to fill as much remaining space as we have – in this case, there's room for five tergites (remember we still need a unit gap between adjacent tergites in order to space them along the abdomen).

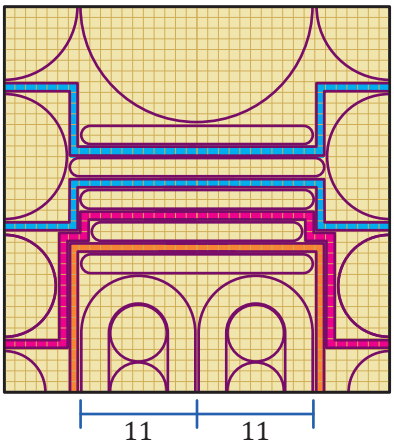
Indeed, this is one of the benefits of including just the minimal number of features in the initial tree, because we now have the flexibility to add only what the paper naturally has space for. In general, this leads to rather efficient designs because the features fit precisely into the usable space that the paper gives us. The cost is that we lose the freedom to specify exactly which features our model contains, because of the possibility that the paper doesn't have room for everything we might want to add.



A circle/river arrangement, including approximate locations for the tail, pedipalps, and tergites.

Adding a Pythagorean stretch

However, in the previous diagram, the rivers don't quite work. For one thing, the rivers between the legs should be the same ones that go between tergites, so these need matching up. Also, the pedipalps ought to be one unit away from the front legs, so we need a new river to separate these features. Let's resolve both of these issues by connecting the corresponding rivers.



The circle/river arrangement after connecting the rivers between the legs and the rivers between the tergites.

The blue rivers work well but the orange river doesn't fill the gap between the front leg and pedipalp nicely. This means there is some wasted space, but it doesn't prevent the arrangement from being valid – the gap is 2 units wide, so a simple pleat of width 1 will hide this paper.

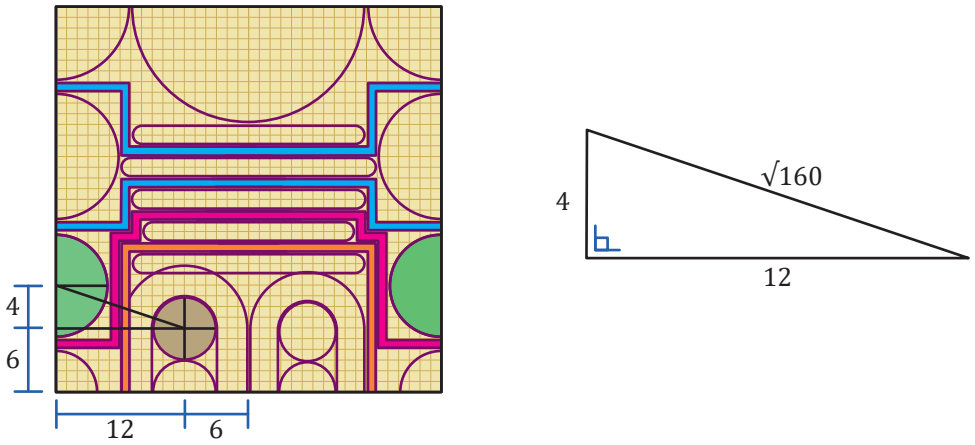
Much more problematic is the fact that each pedipalp is symmetric, and therefore its total width must be an even number, no matter how long its flap is. But the available space is limited by the orange and magenta rivers, which leave only 11 units free.

It would be nice if we could squeeze just 1 extra unit out of this arrangement somehow, so that the paper needed for each pedipalp is 12 units wide, resulting in pedipalps which are 6 units long. If we suppose that we can get an extra unit somehow, this precisely determines where the centre of the upper circle in the

pedipalp (the upper claw) should be: 6 units from the bottom edge and 6 units to the left of the central vertical line. This is the brown circle in the image below.

The key issue is that the distance between the centre of this brown circle and the centre of the green circle needs to be at least as large as the following sum: the length of the pedipalp (6) + the width of the orange river (1) + the width of the magenta river (1) + the length of the green leg (5) = 13. But the centre of the green circle is only 12 units from the left raw edge, so we cannot get this distance by considering the horizontal distance alone.

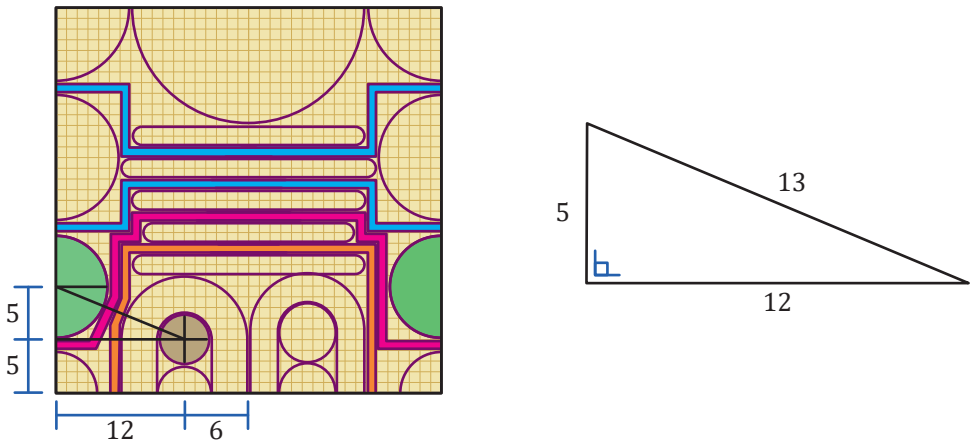
What about diagonally then? The actual distance between the circle centres is the hypotenuse (long side) of a right-angled triangle and can be calculated with Pythagoras' theorem, using both the horizontal and vertical distances between the circle centres. After a quick calculation, we find that the length is ≈ 12.65, which is unfortunately still less than the 13 we need. So even diagonally, there isn't quite enough space.



The distance between the centres of the green and brown circles is $\sqrt{(12^2+4^2)} = \sqrt{160} < 13$.

What if we move the centre of the brown circle down one unit? This increases the vertical distance between the green and brown circle centres to 5 and gives a new hypotenuse of exactly 13 units. We've stumbled across the 5-12-13 triangle, which is an example of a **Pythagorean triple** – a right-angled triangle where each side is an integer. This looks like it's worked: we've found a geometric gem, and by moving the pedipalp down, we've also removed the overlap between the pedipalp and lowest tergite flap, which you may have noticed crept into the above diagram when we made the pedipalp flaps slightly larger.

Using a diagonal distance like this to get more distance between points is called a **Pythagorean stretch**, and if an exact Pythagorean triple is used (like here), we call it a **perfect Pythagorean stretch**. Personally, I find that Pythagorean stretches which aren't perfect are needlessly complicated (it's far more work to get references to fold a non-perfect Pythagorean stretch, and the structure contains fewer axial folds). In almost all circumstances, flaps can be arranged so that an exact Pythagorean triple works.



By moving the brown circle down one unit, the distance between the centres of the green and brown circles is now $\sqrt{(12^2+5^2)} = \sqrt{169} = 13$. There are no longer any overlapping circles or rivers.

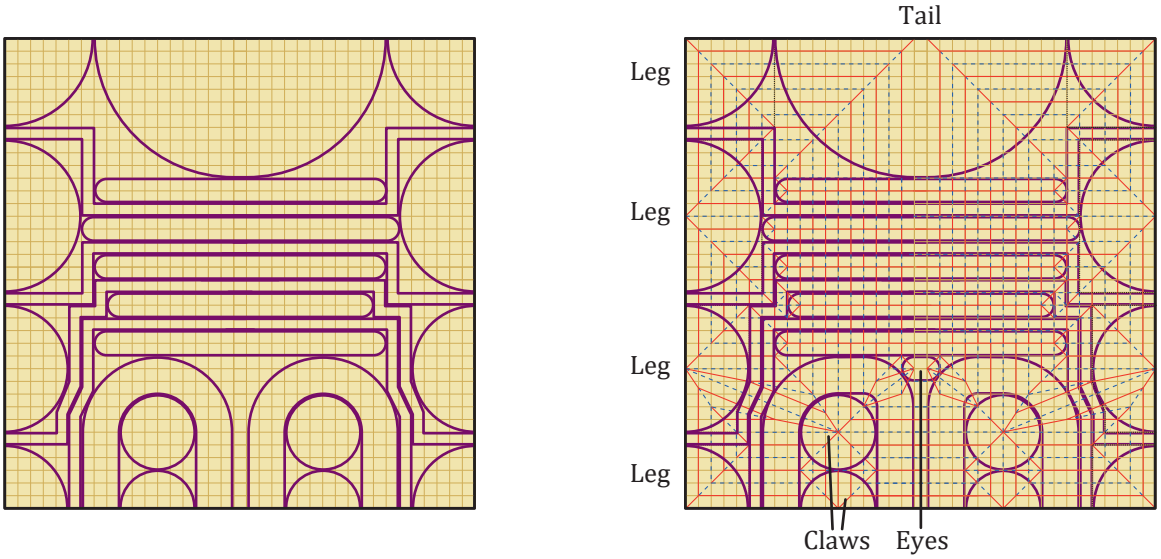
A parity problem

But something unwanted has occurred in this new arrangement: the brown circle is now 5 units from the bottom edge. But this distance is twice the length of each claw, so it should be an even number (if we're sticking to the grid). The vertical location of the brown circle is determined by both the green circle's centre, which will always be an even number of units from the top edge, due to the consecutive leg lengths, and the additional 5 units from the 5-12-13 triangle. The sum of these distances will always be odd, even with different leg lengths. This leaves an odd number of squares at the bottom to complete the even-numbered grid, but we want an even number instead. We can't get around this problem with our current 36-unit grid.

But we have one final trick: we can add one extra unit to the grid. This doesn't come without costs – folding a 37×37 grid is *very* unorthodox, but it provides an even distance between the claws, resolving the parity issue. In fact, it does more than this: the extra space means we can increase the length of the front leg by one unit, and so it now touches the surrounding rivers.

Adding an extra unit to the grid means we have a bonus vertical strip down the centre of the paper. This adds width to the scorpion's body and actually means there are now two axes on either side of this strip. This is unusual, but there's no meaningful downside to it.

So we have the final arrangement, shown on the left below. All of the circles and rivers now work and can be used to fold a base for the Scorpion. For the final crease pattern, I've also added an extra flap for the eyes using another Pythagorean stretch. In case anyone's checking, I'll also mention that the sequence for the tergites in the Scorpion diagrams doesn't use these creases exactly, because although the crease pattern illustrates the flap structure well, it is rather tricky to fold.



Left: The final circle/river arrangement for the Scorpion. Right: The full crease pattern.

It's worth dwelling on the parity issue just a moment longer though. Isn't it strange that in a box-pleated design, where we almost always alternate between valleys and mountains, both the front legs and the back legs end up at the same 'valley' level, even though they are 37 units – an odd number – apart? The reason for this is that the Pythagorean stretch disrupts the usual alternating pattern. The height of the triangle was an odd number, so the parity flipped.

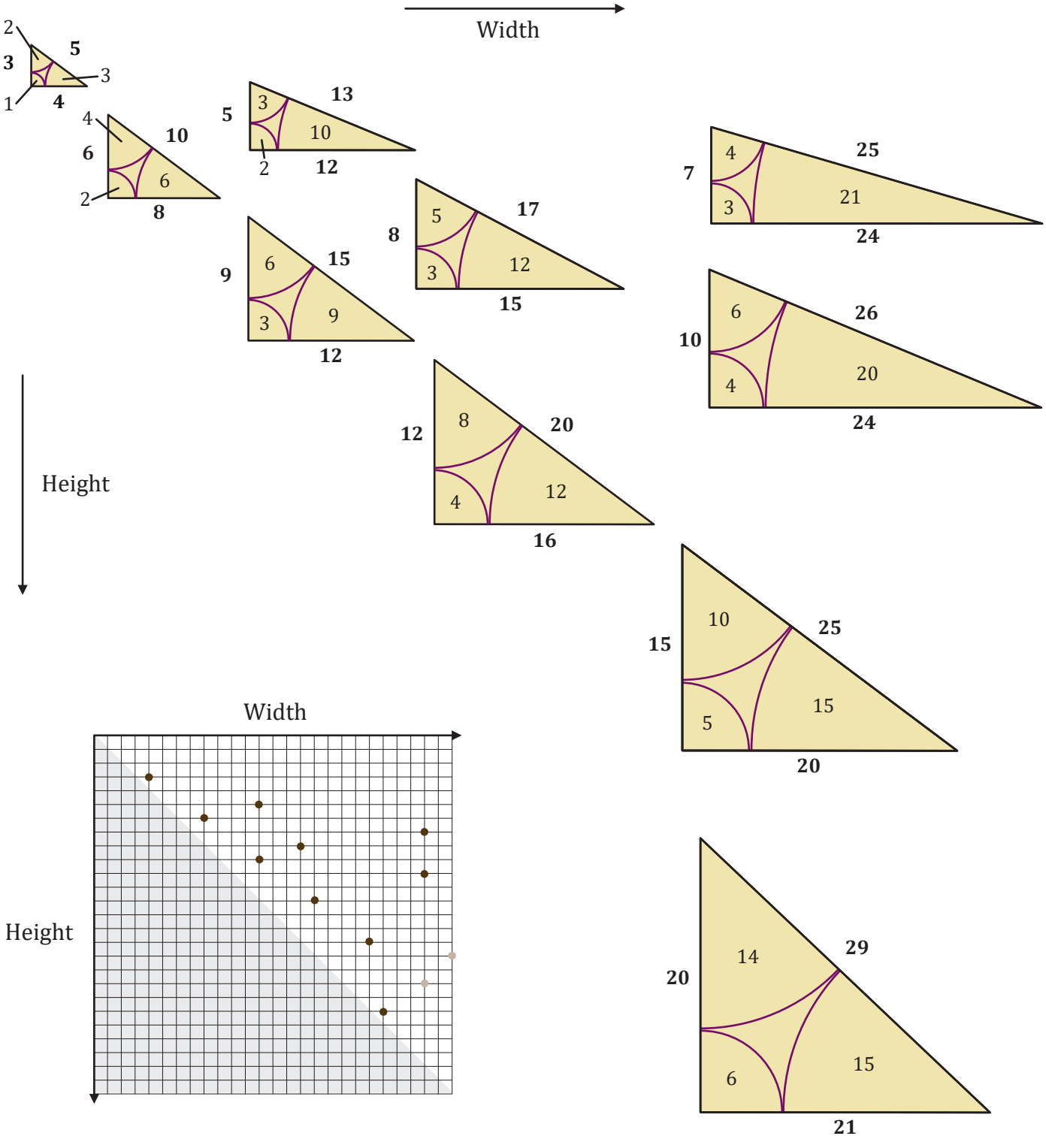
Most symmetric box-pleated designs use an even grid number, so that one of the grid lines falls exactly in the centre. But whenever a Pythagorean stretch uses a **primitive** Pythagorean triple – a triangle where the greatest common factor of the three side lengths is 1 – it must be the case that one of the vertical or horizontal sides is odd. In this case, it may be that using an odd grid number is preferable. Each non-primitive Pythagorean triple is just a multiple of a primitive Pythagorean triple (much like how each non-prime number can be expressed as a multiple of prime numbers), and multiplying a primitive Pythagorean triple by an even number will prevent this problem. Another way around the parity issue would be to use an even number of primitive triples, so that the parity flips an even number of times.

Common triples

Although they can be calculated, it's helpful to have a list of useful Pythagorean triples at your disposal.

Below are the triples where the hypotenuse is less than 30. I've never seen a design use more than this, but by all means, go ahead.

The radii of the circular arcs are also shown, which are the lengths of the three flaps if the triangle is folded into a rabbit ear.

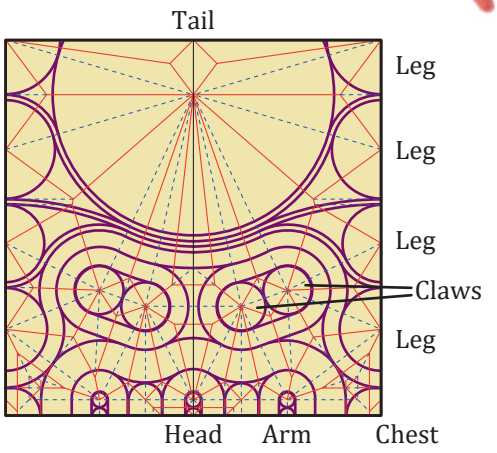


Aqrabuamelu

First time: 50cm/20''

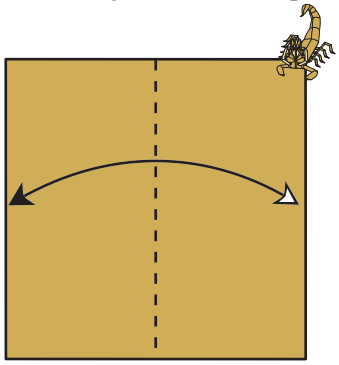
Paper preferences:
- Duo
- Thin
- Shapeable
- Tearproof

Recommended papers:
- Double tissue
- Foil-backed paper

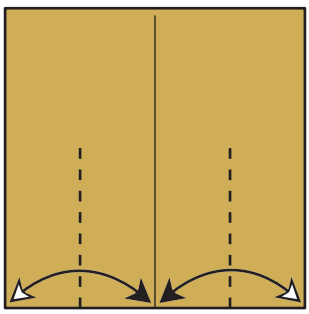


Aqrabuamelu are powerful creatures in Babylonian mythology, with the head, torso, and arms of a human and the body of a scorpion. While typically depicted as male, I opted for a female version here.

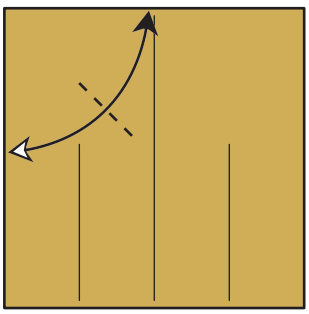
Start body colour side up.



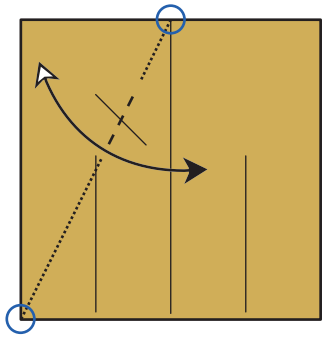
1. Fold and unfold the central vertical line.



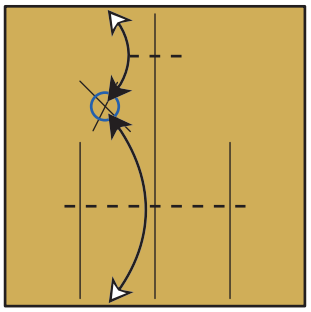
2. Fold the raw edges to the crease, only marking firmly in the lower half of the paper, then unfold.



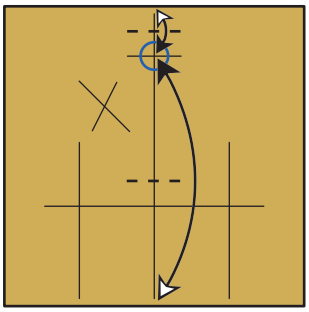
3. Fold and unfold a small section of the downward diagonal, marking firmly only where shown.



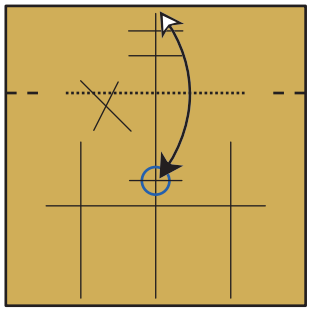
4. Make a fold-line which connects the circled points, mark firmly only where the line crosses the previous crease, then unfold.



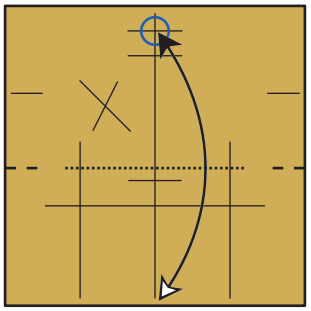
5. Fold the top and bottom raw edges to the circled point, mark firmly only where shown, then unfold.



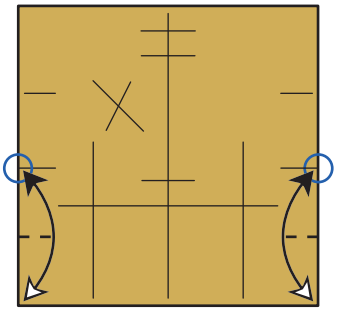
6. Fold the top and bottom raw edges to the circled crease, mark firmly only in the centre, then unfold.



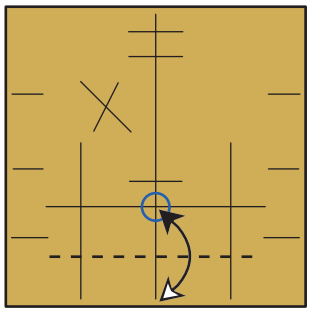
7. Fold the top raw edge to the circled crease, mark firmly only at the raw edges, then unfold.



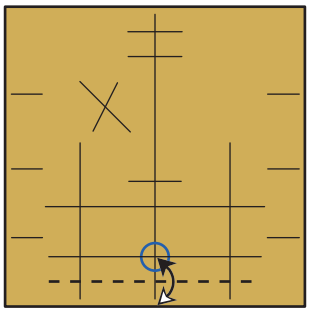
8. Fold the bottom raw edge to the circled crease, mark firmly only at the raw edges, then unfold.



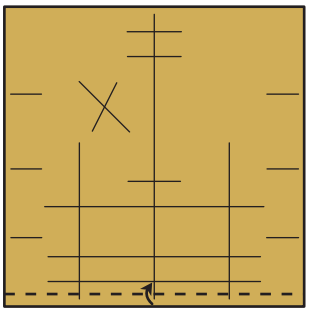
9. Fold the bottom raw corners to the creases you just made, mark firmly only at the raw edges, then unfold.



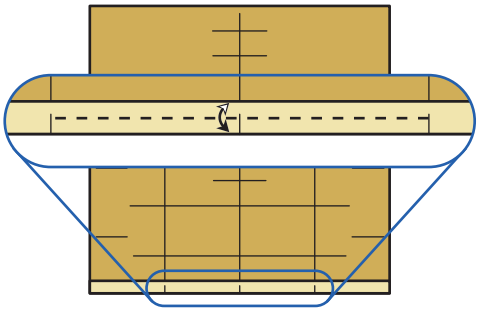
10. Fold the bottom raw edge to the circled crease, mark firmly only in the central half, then unfold.



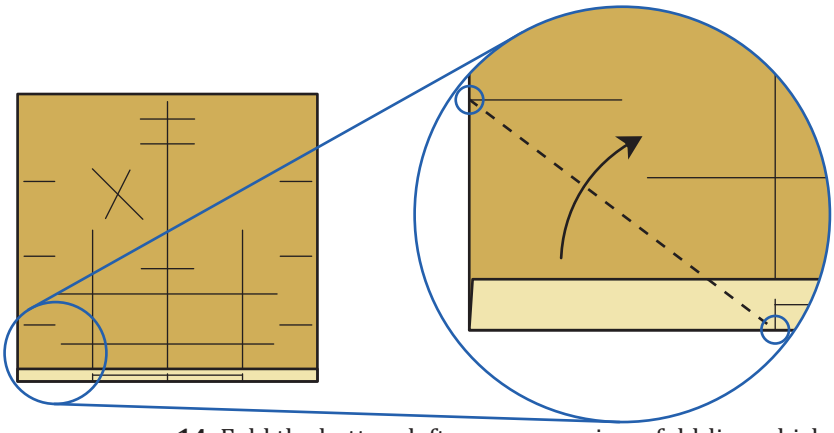
11. Fold the bottom raw edge to the crease you just made, mark firmly only in the central half, then unfold.



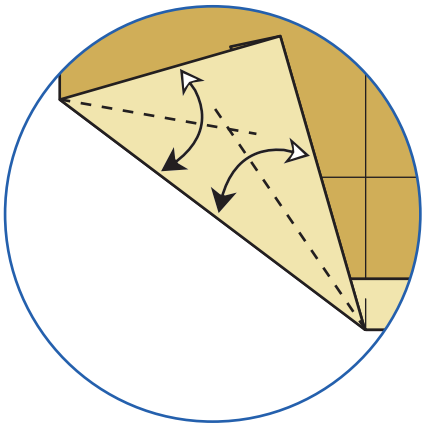
12. Fold the bottom raw edge to the crease you just made (don't unfold).



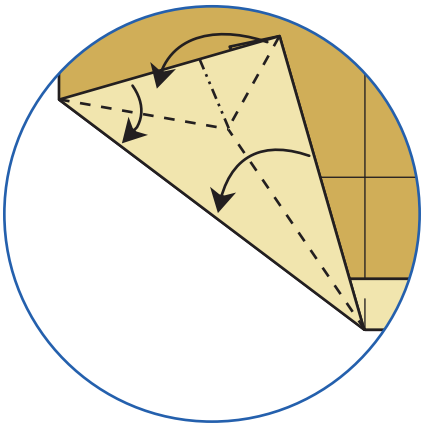
13. Fold the middle of the raw edge down to the bottom, then unfold.



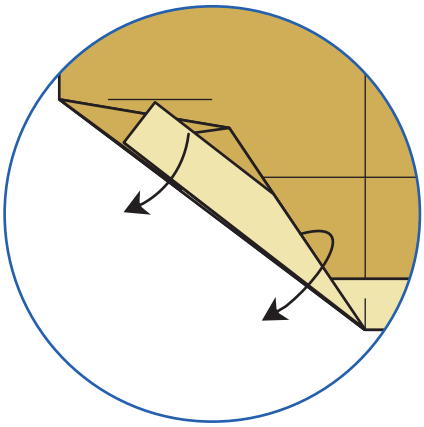
14. Fold the bottom left corner up using a fold-line which connects the circled points.



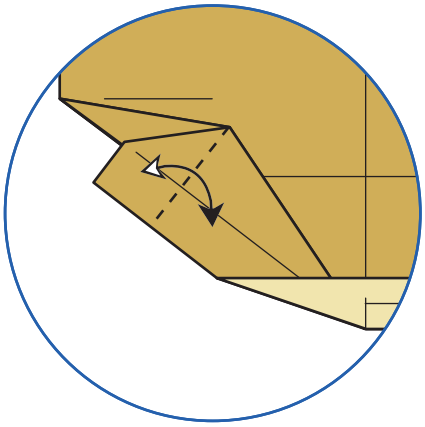
15. Fold and unfold two angle bisectors.



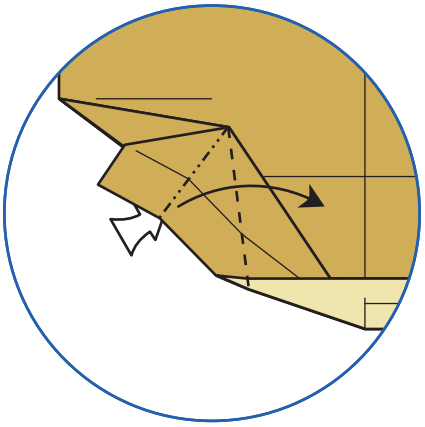
16. Rabbit-ear the corner to the left.



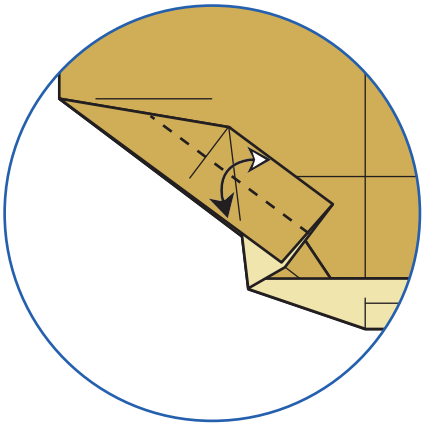
17. Unfold the raw edge.



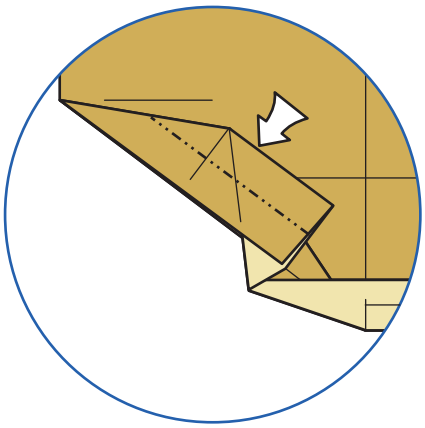
18. Fold and unfold.



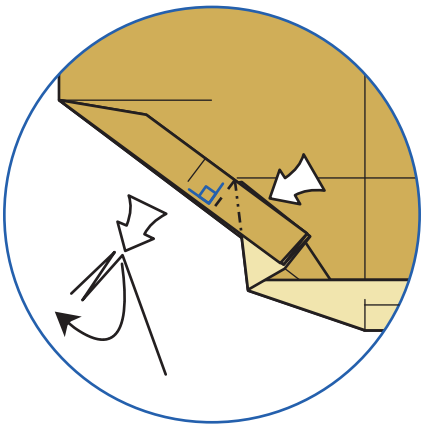
19. Swivel-fold: pinch the crease you just made into a mountain fold and bring it the the right.



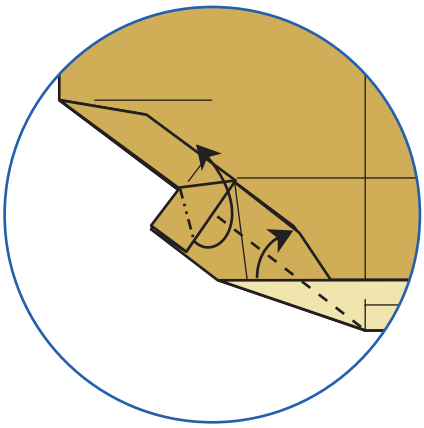
20. Fold and unfold.



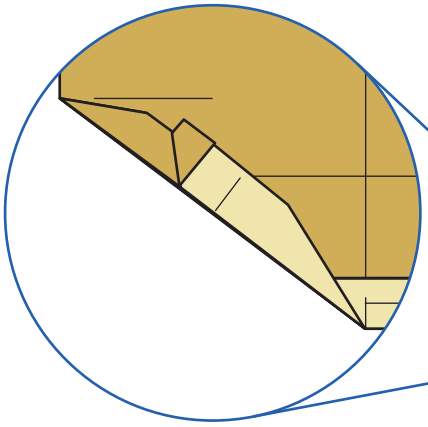
21. Open-sink the edge.



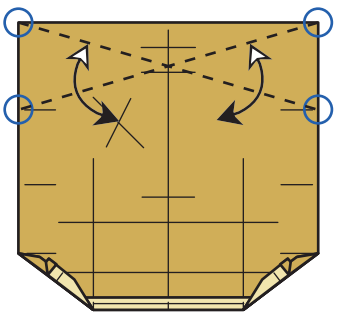
22. Swivel-fold the edges, opening the **second** layer.



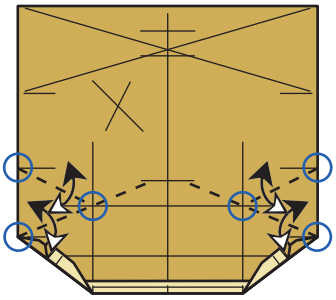
23. Swivel-fold the edge up.



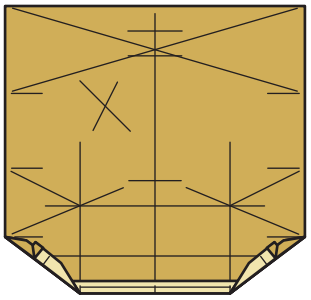
24. Repeat steps 14 to 23 on the right.



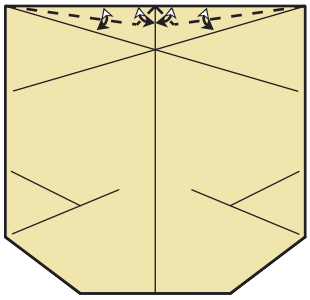
25. Fold and unfold two fold-lines which connect the circled points.



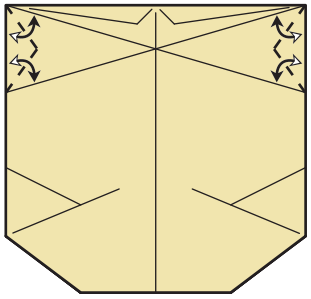
26. Fold and unfold four fold-lines which connect the circled points. Extend the lower fold-lines upwards, as shown.



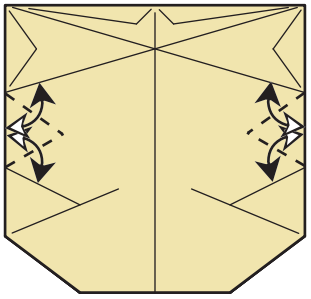
27. Several creases will no longer be shown. Turn the paper over.



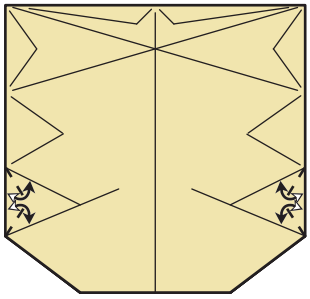
28. Fold and unfold four angle bisectors.



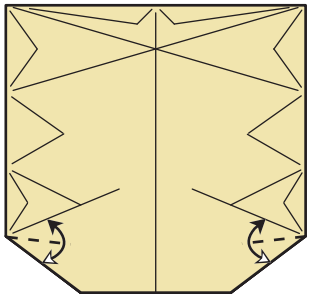
29. Fold and unfold four angle bisectors.



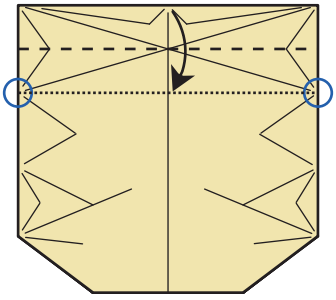
30. Fold and unfold four angle bisectors.



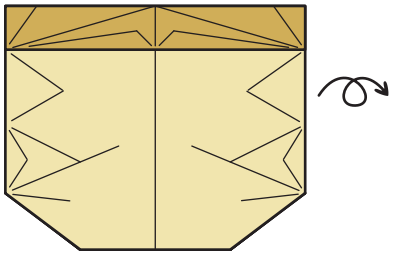
31. Fold and unfold four angle bisectors.



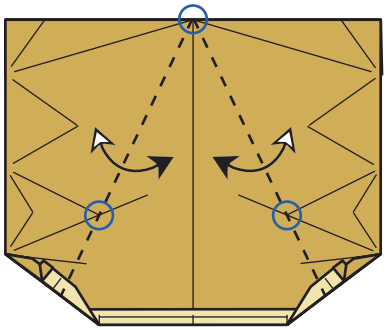
32. Fold and unfold two angle bisectors.



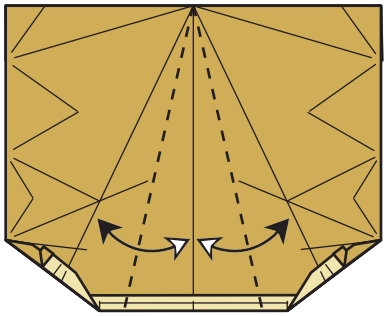
33. Fold the top raw edge down.



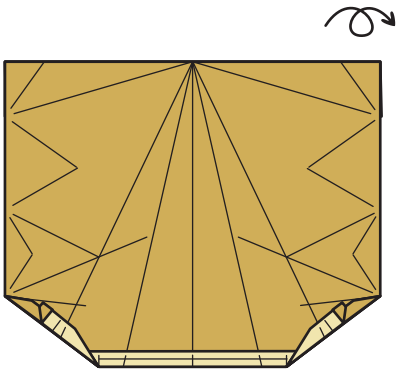
34. Turn the paper over.



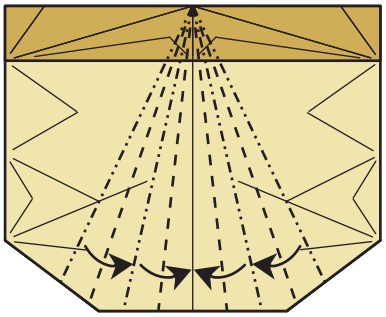
35. Fold and unfold two fold-lines which connect the circled points.



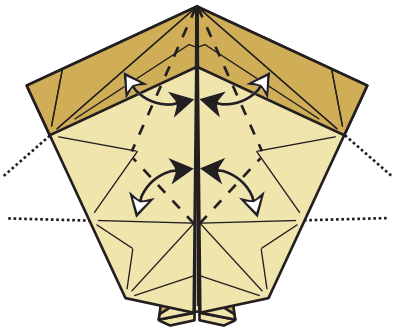
36. Fold and unfold two angle bisectors.



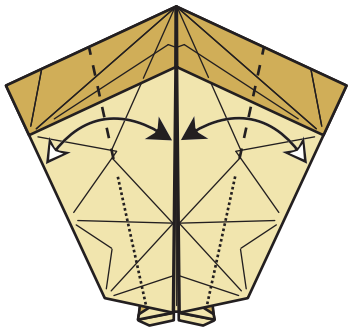
37. Turn the paper over.



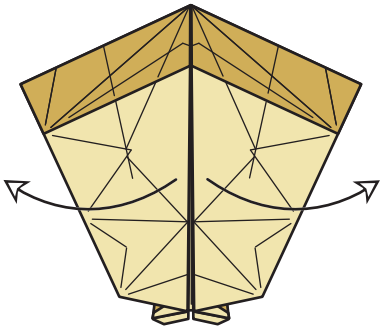
38. Pleat the paper to make four new angle bisectors.



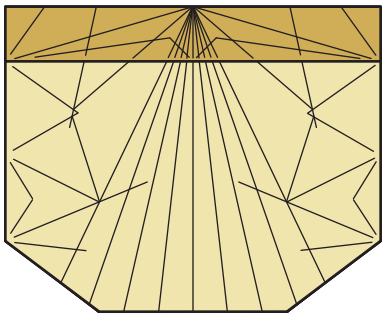
39. Fold and unfold four angle bisectors. Only fold the lower fold-lines on the nearest white layer.



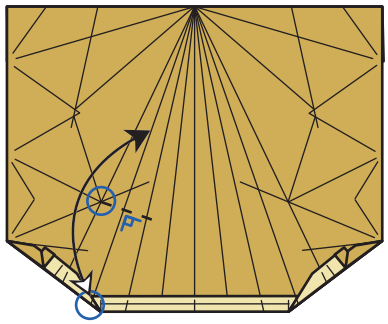
40. Fold the raw edges to the centre, only marking firmly where shown.



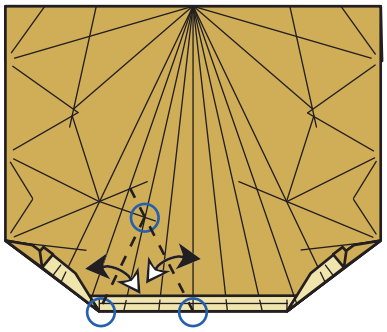
41. Unfold step 38.



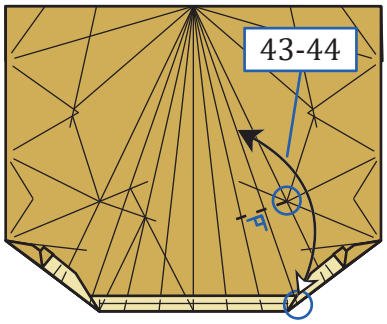
42. Turn the paper over.



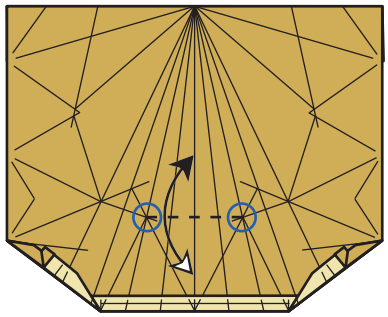
43. Make a fold-line through the upper circled point so that the indicated mountain crease folds onto itself, then unfold. (Note that this is not an extension of the crease made in step 26.)



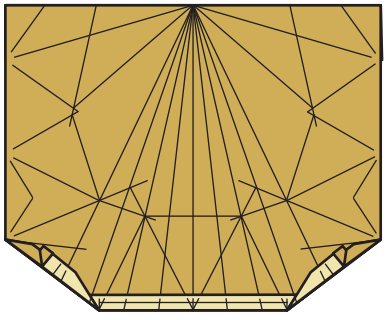
44. Fold and unfold two lines which connect the circled points. Extend the right fold-line upwards, as shown.



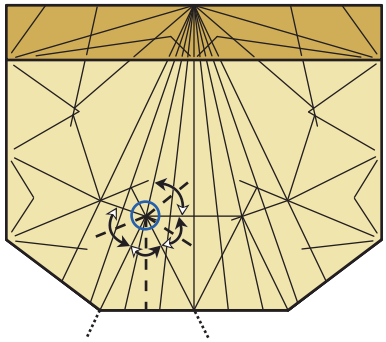
45. Repeat steps 43 and 44 on the right.



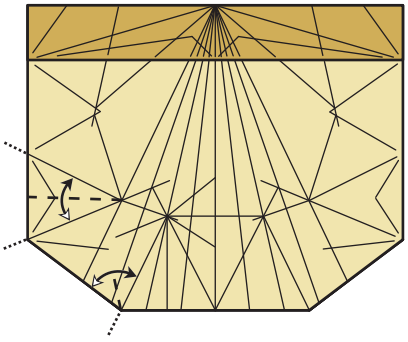
46. Fold and unfold a horizontal line through the circled points.



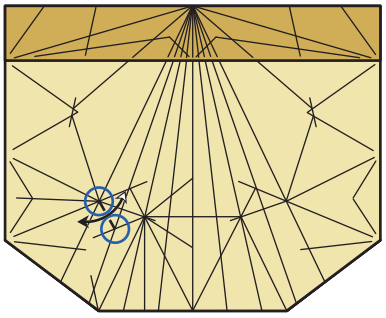
47. Turn the paper over.



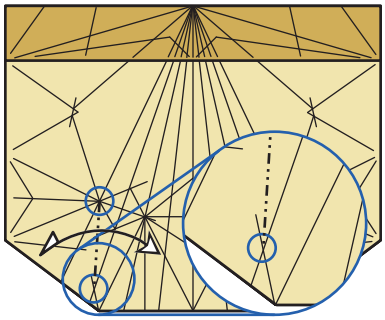
48. Fold and unfold four angle bisectors around the circled point.



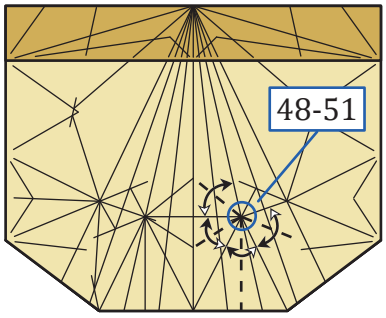
49. Fold and unfold two angle bisectors.



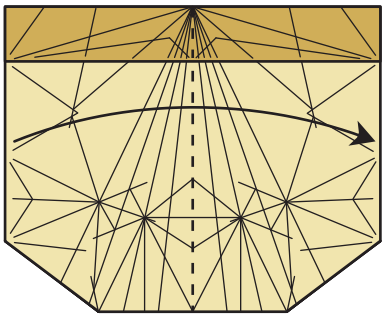
50. Make a fold-line which connects the circled points, then unfold.



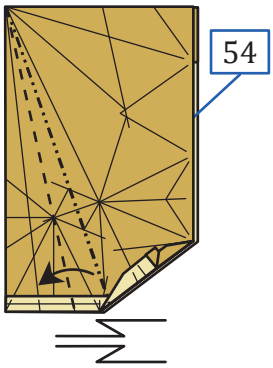
51. Pinch a **mountain fold** between the circled points.



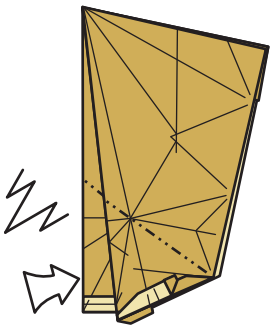
52. Repeat steps 48 to 51 on the right.



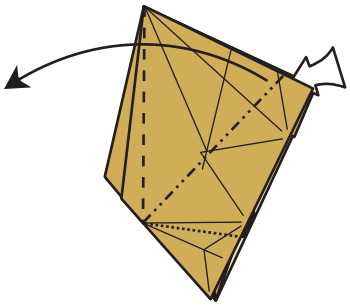
53. Fold the left half onto the right half.



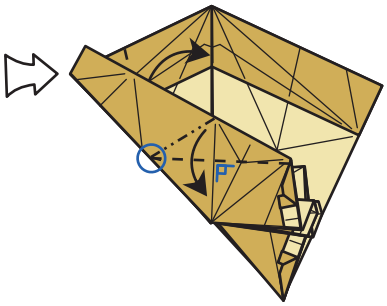
54. Pleat the right portion to the left using existing creases. Repeat behind.



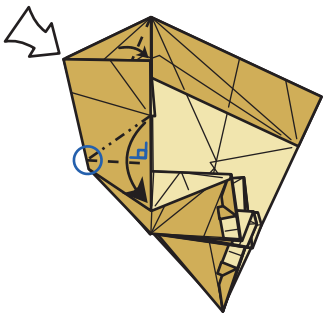
55. Mixed-reverse-fold the paper using existing creases.



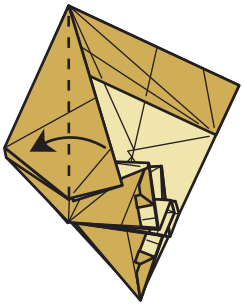
56. Swivel-fold the near layer to the left. You will need to extend the existing mountain fold-line and create a new hidden valley fold, but don't fold either of these lines firmly.



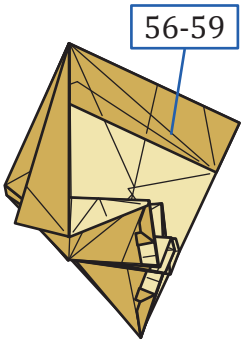
57. Make a new valley fold that passes through the circled point and swivel-fold the raw edge in.



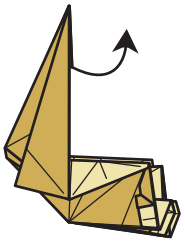
58. Make a new valley fold that passes through the circled point and swivel-fold the edge to the right.



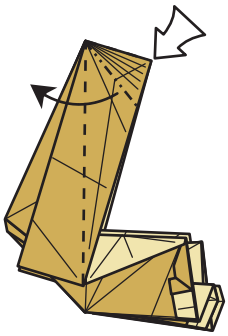
59. Fold the edge to the left.



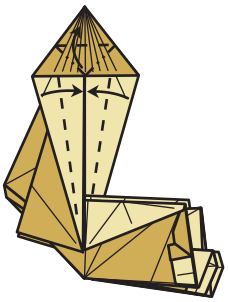
60. Repeat steps 56 to 59 behind.



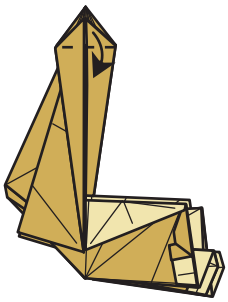
61. Pull out the raw edge.



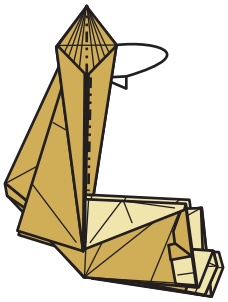
62. Squash-fold the edge.



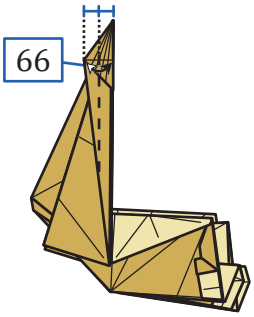
63. Petal-fold the raw edge up to make a corner.



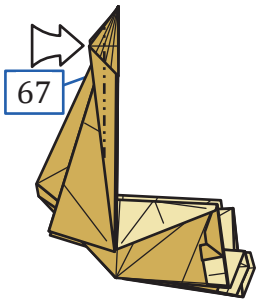
64. Fold the corner down.



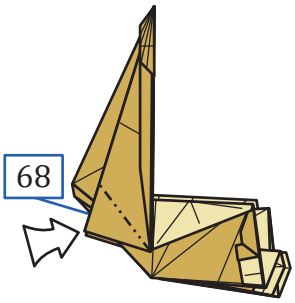
65. Mountain-fold the edge behind.



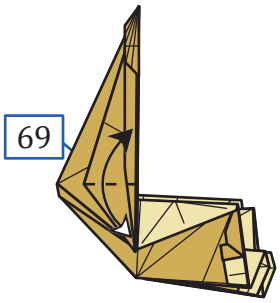
66. Fold the narrow flap in half and unfold. Repeat behind.



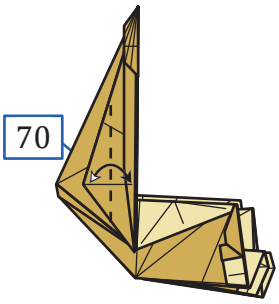
67. Closed-sink the edge using the crease you just made. Repeat behind.



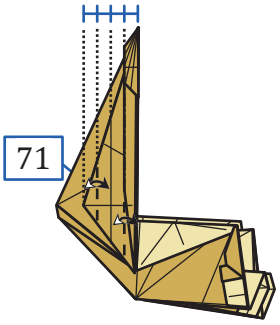
68. Reverse-fold. Repeat behind.



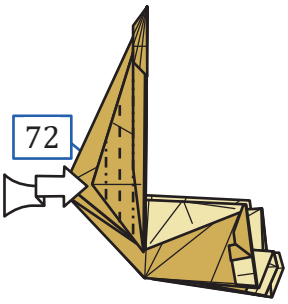
69. Fold and unfold. Repeat behind.



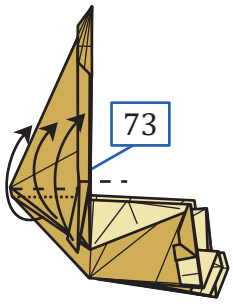
70. Fold the flap in half and unfold. Repeat behind.



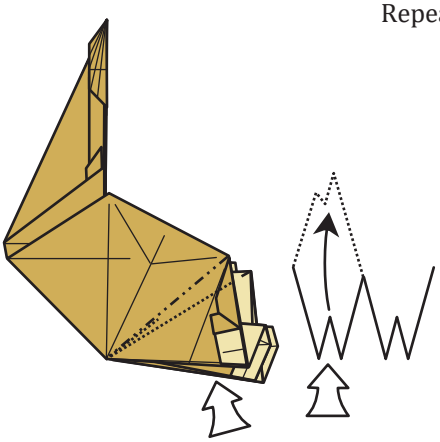
71. Fold and unfold the flap into quarters. You may need to lift the nearest layers out of the way to do this neatly. Repeat behind.



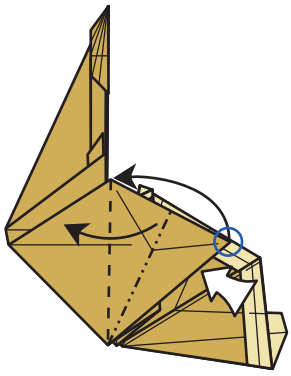
72. Open-sink in and out using creases from steps 70 and 71. Repeat behind.



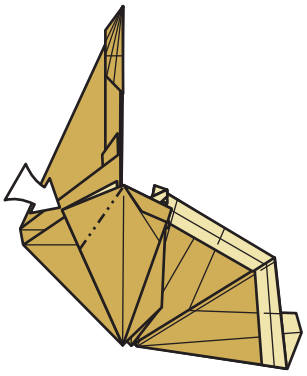
73. Fold **three** flaps up, one at a time. Repeat behind.



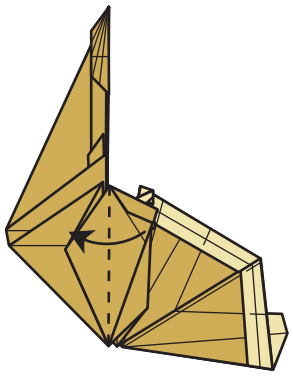
74. Mixed-reverse-fold the pleats in the near half of the paper using the extended creases from steps 26 and 44. The paper won't lie completely flat until after step 81.



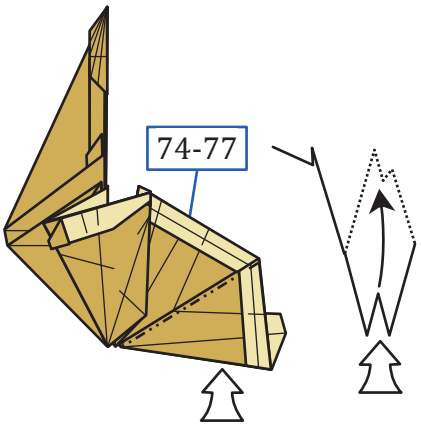
75. Squash-fold the circled corner to the centre. Only fold firmly in the near layer where the creases already exist.



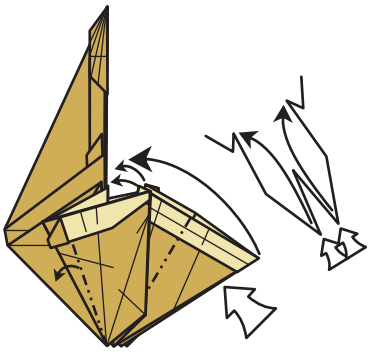
76. Reverse-fold.



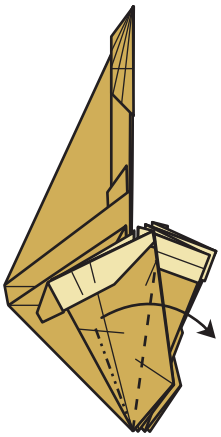
77. Gently fold the layers to the left using the vertical crease.



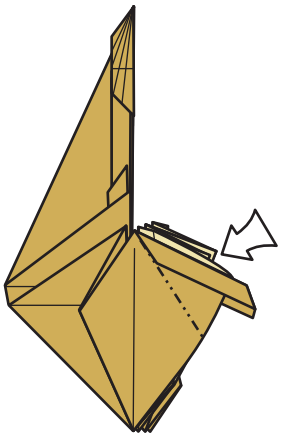
78. Repeat steps 74 to 77 behind.



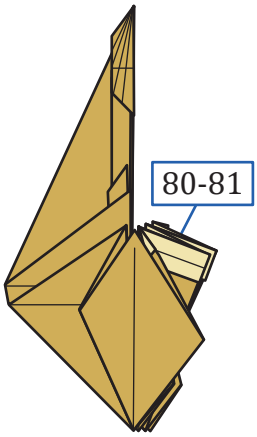
79. Mixed-reverse-fold using creases from step 48 to bring three corners together at the centre, as shown. The middle layers will flatten (but not the near or far layers).



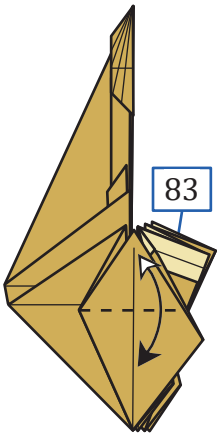
80. Swivel-fold the edge to the right using the crease made in step 51. Flatten the paper to make a new mountain fold, but only do this at the bottom of the paper.



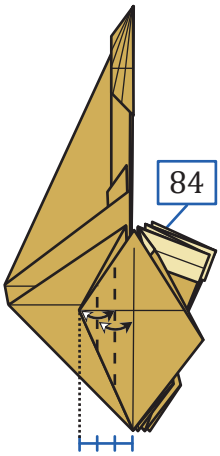
81. Reverse-fold the edge so that it becomes vertical. You will need to make a new fold-line to achieve this, but the near layers will at last lie flat.



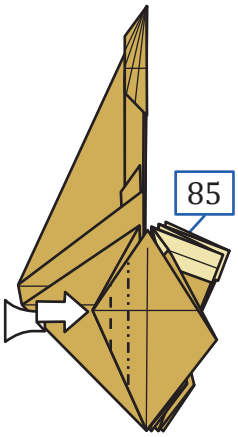
82. Repeat steps 80 and 81 behind.



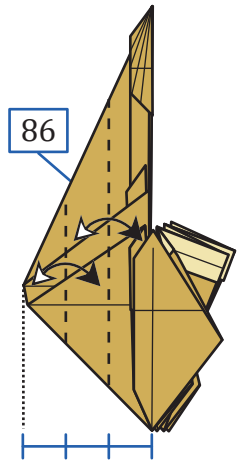
83. Fold and unfold. Repeat behind.



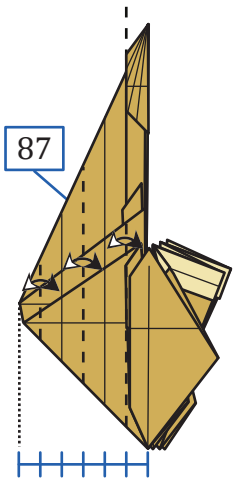
84. Fold and unfold the flap roughly into thirds. Repeat behind.



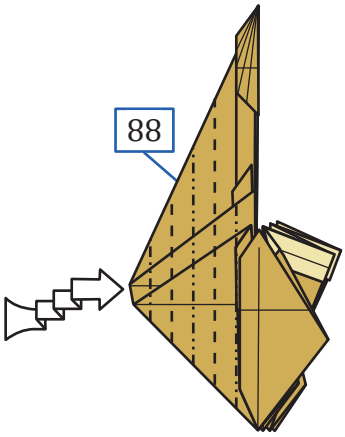
85. Open-sink the flap in and out using the creases you just made. Repeat behind.



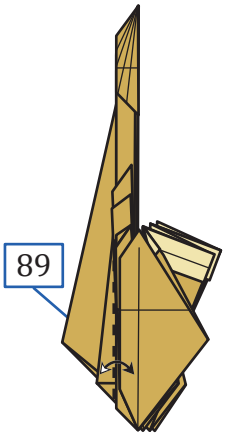
86. Fold and unfold the flap roughly into thirds. Repeat behind.



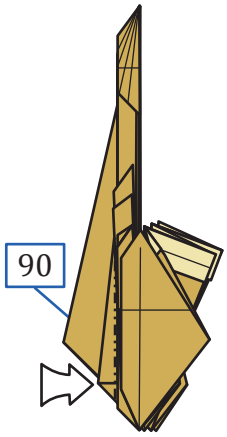
87. Fold and unfold the flap roughly into sixths. You may need to fold some of the nearer flaps out of the way for an accurate result. Repeat behind.



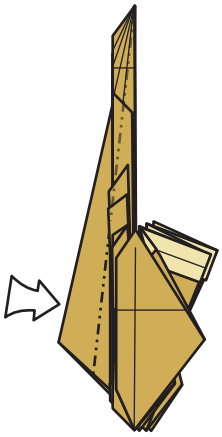
88. Open-sink in and out using the creases made in steps 86 and 87. Repeat behind.



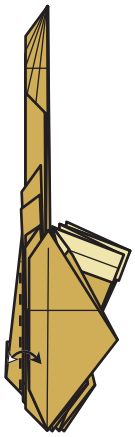
89. Fold the edge to the right over the nearer layers, then unfold. Repeat behind.



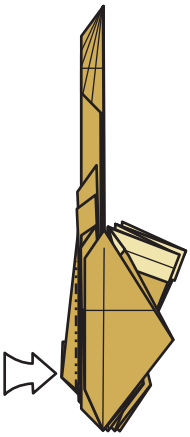
90. Open-sink using the creases you just made. Repeat behind.



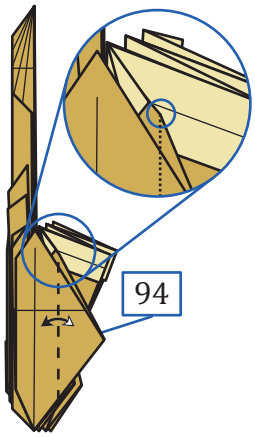
91. Open-sink.



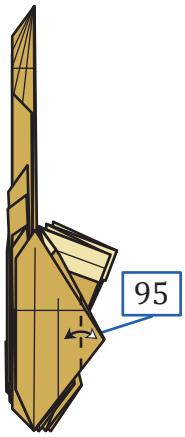
92. Fold the edges to the right over the nearer flaps, mark firmly through all layers, then unfold.



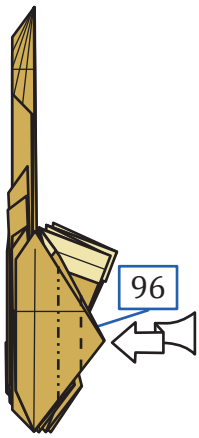
93. Open-sink using the creases you just made.



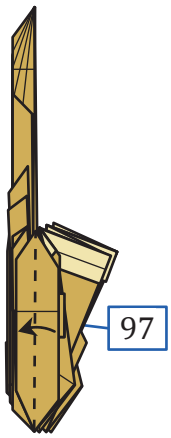
94. Fold and unfold the flap using a vertical fold-line through the circled corner. (There are some hidden flaps which make this tricky at the top, so only fold up as high as you can manage.) Repeat behind.



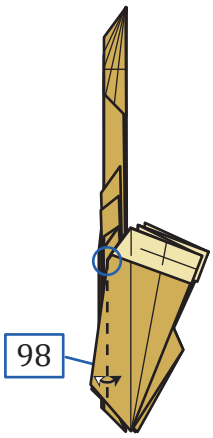
95. Fold and unfold to the crease you just made. Repeat behind.



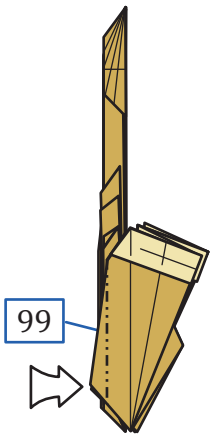
96. Open-sink in and out using the creases from steps 94 and 95. Repeat behind.



97. Fold the connected edges to the left. Repeat behind.

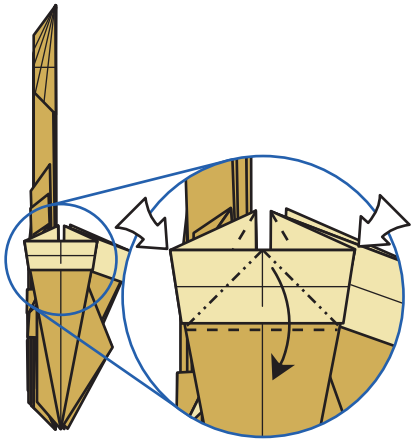


98. Fold a vertical line through the circled point, then unfold. Repeat behind.

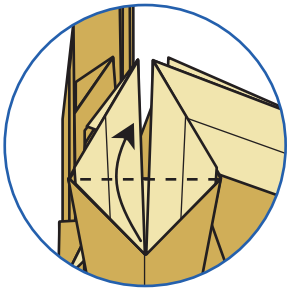


99. Open-sink using the creases you just made. Repeat behind.

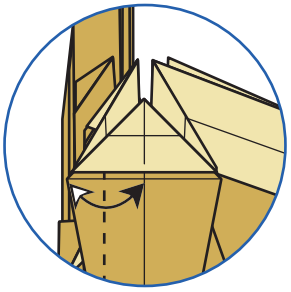
100. Squash-fold.



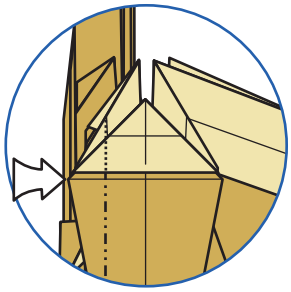
101. Petal-fold – each of these fold-lines are new.



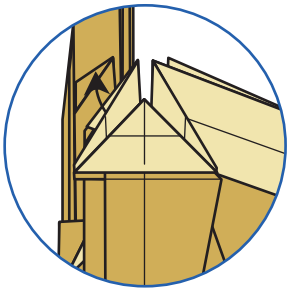
102. Fold the corner up.



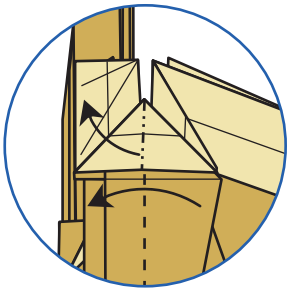
103. Fold and unfold the left side in half, but only mark the coloured layers firmly.



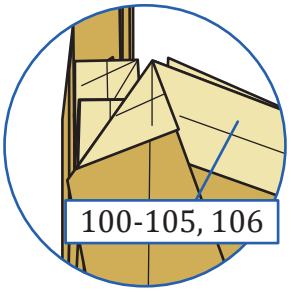
104. Open-sink, but don't fold the white layer.



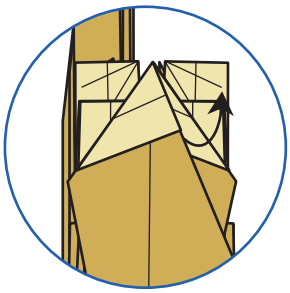
105. Carefully pull the raw edge out.



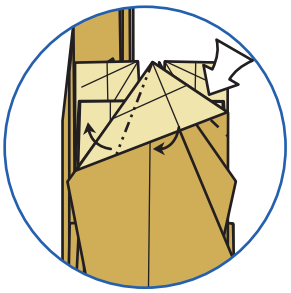
106. Lift the raw edge and fold the connected layers to the left.



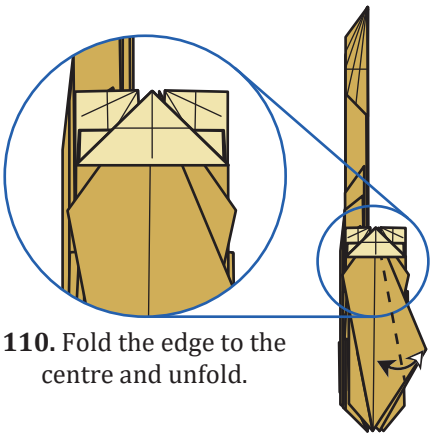
107. Repeat steps 100 to 105 behind, flipping left and right, and then step 106 (not flipping left and right).



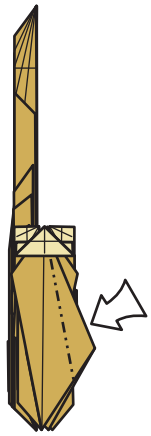
108. Carefully pull the raw edge out.



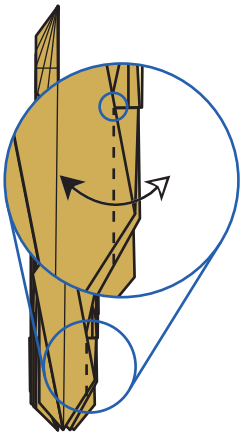
109. Swivel-fold so that the raw edge becomes horizontal.



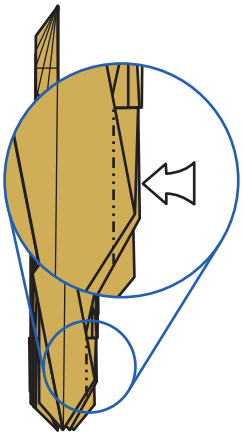
110. Fold the edge to the centre and unfold.



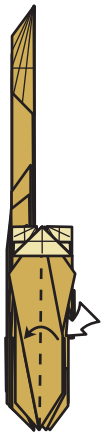
111. Open-sink the edge using the creases you just made.



112. Fold the narrow edge using a vertical line through the circled point, then unfold.



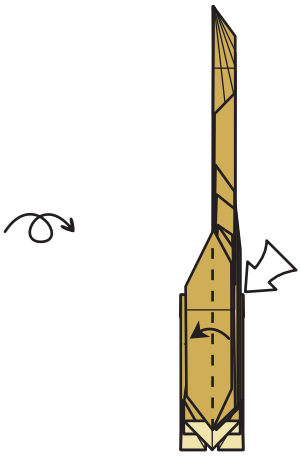
113. Open-sink the narrow edge using the creases you just made.



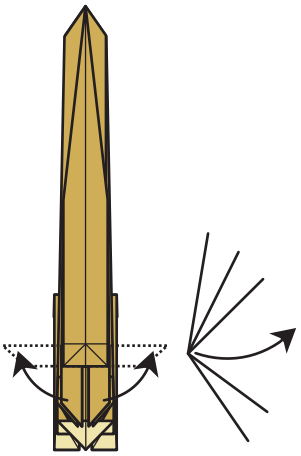
114. Open the layers symmetrically.

115. Fold the connected flaps down.

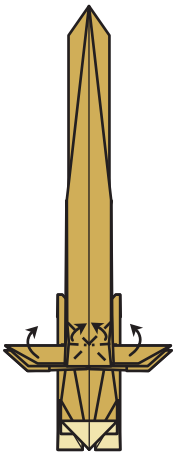
116. Turn the paper over.



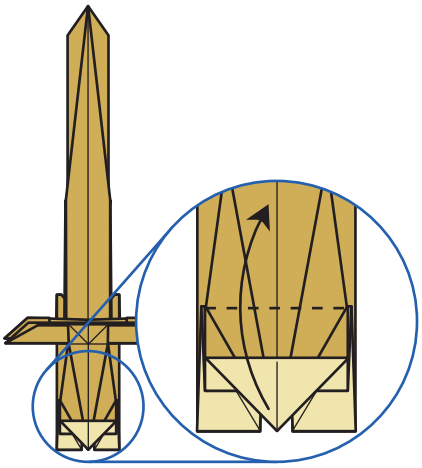
117. Spread the layers evenly.



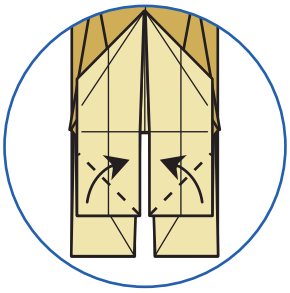
118. Reverse-fold the two thick flaps, sending the central edge from the outer point upwards.



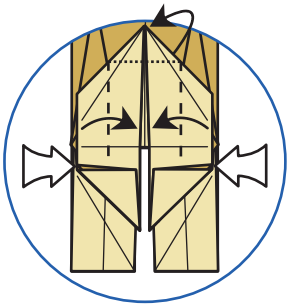
119. Fold the flaps upwards, and make a small Waterbomb Base in the middle of the paper in as many layers as possible.



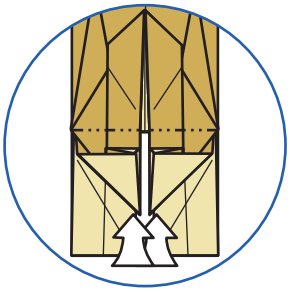
120. Fold one flap upwards.



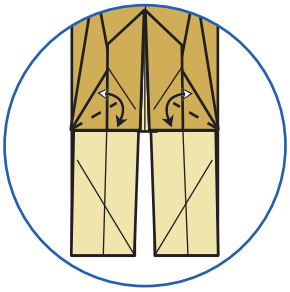
121. Fold the corners in.



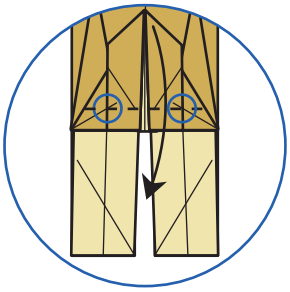
122. Very carefully fold the raw edge in to the folded edge along an existing crease: reverse-fold at the bottom on each side and gently wrap the paper over the top to achieve this. Be patient with this step.



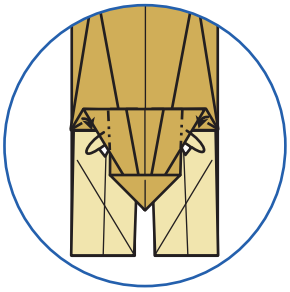
123. Reverse-fold the corners in.



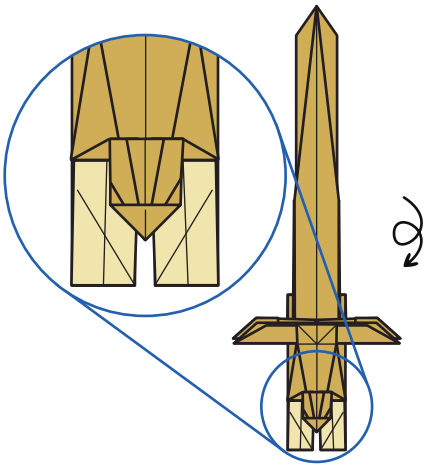
124. Fold and unfold an angle bisector on each side.



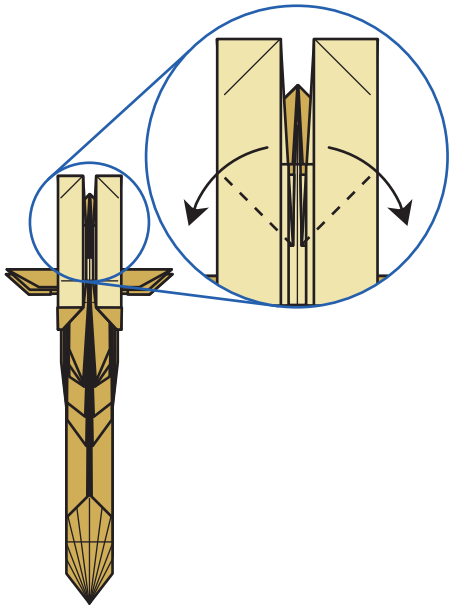
125. Fold the corner down using a fold-line which goes through the circled points.



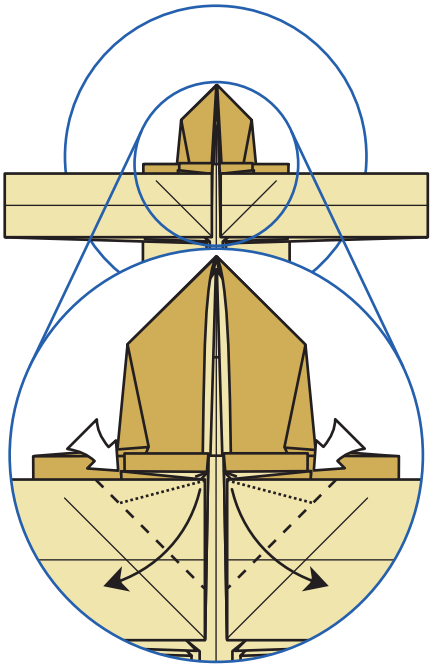
126. Swivel-fold the edge underneath using creases from step 124.



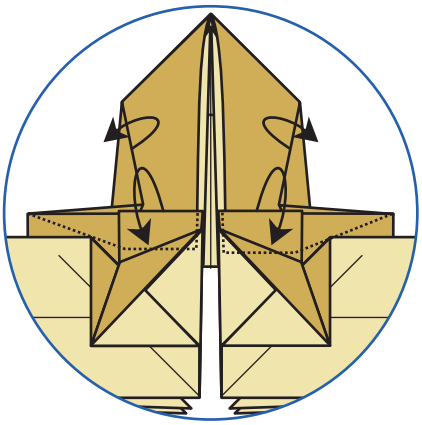
127. Turn the paper over from top to bottom.



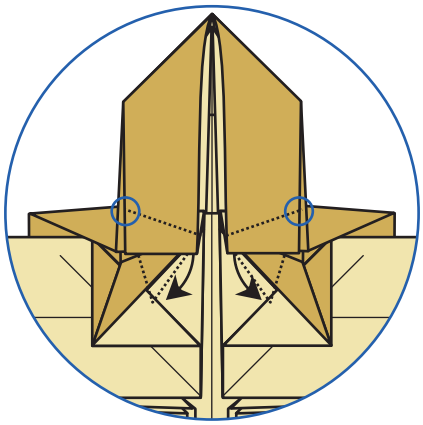
128. Fold the flaps to the sides.



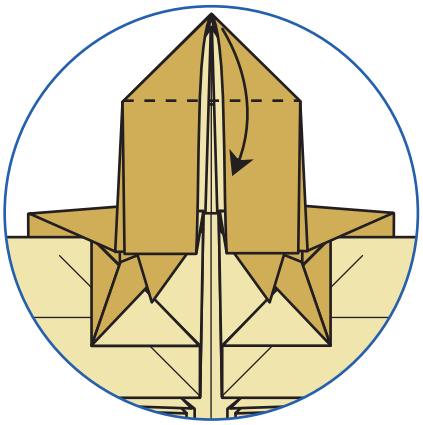
129. Swivel-fold the corners down.



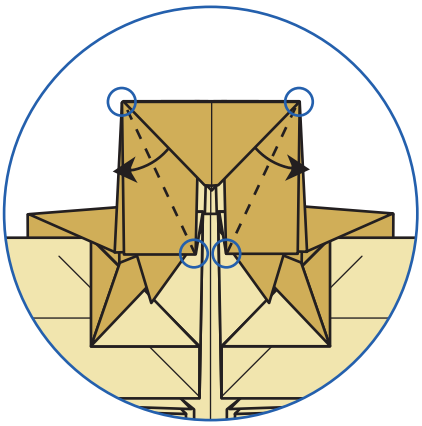
130. Pull the near layers on the left and right to the front by flipping the valleys into mountains and sinking the edge on each side behind the near layer.



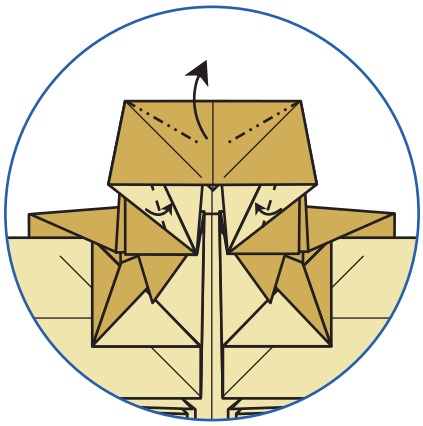
131. Pull the hidden corners down by pivoting the paper about the circled points.



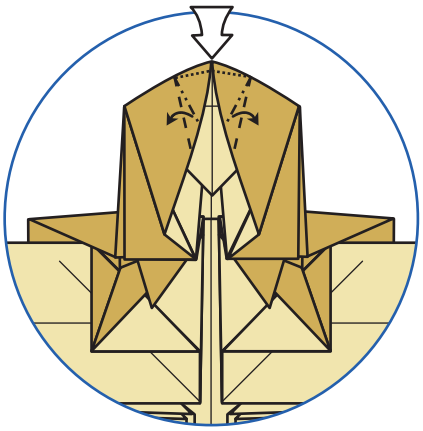
132. Fold the top corner down.



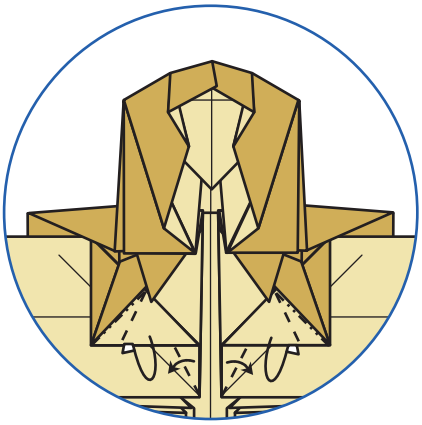
133. Pull out the raw edge (but not the next layer) on each side.



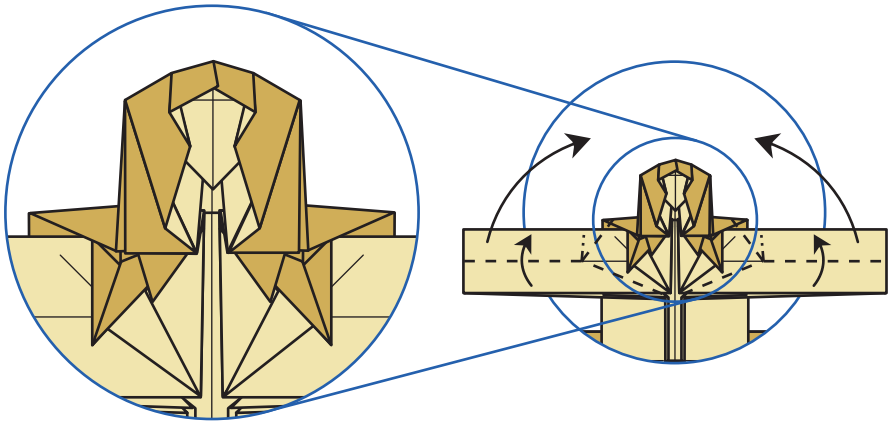
134. Petal-fold the raw edge using new creases. There are no references, and do not flatten the paper at the top.



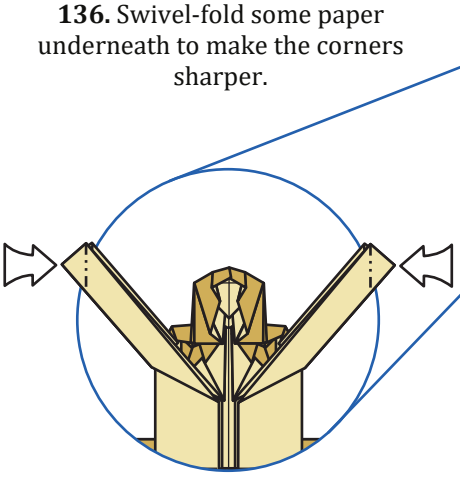
135. Open the paper at the top of the head and flatten; use two slanted fold-lines rather than a horizontal fold-line so that the top of the head is rounded.



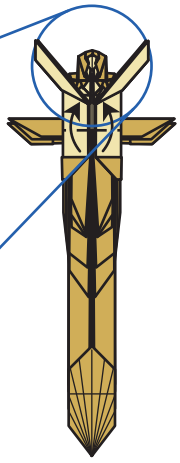
136. Swivel-fold some paper underneath to make the corners sharper.



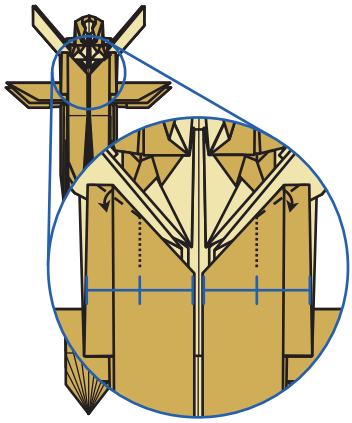
137. Rabbit-ear the arms upwards.



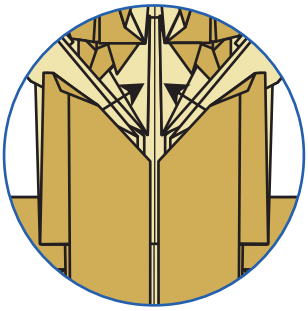
138. Reverse-fold the corners.



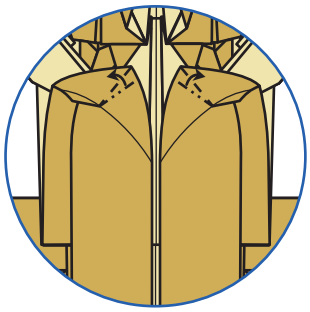
139. Fold two small flaps upwards.



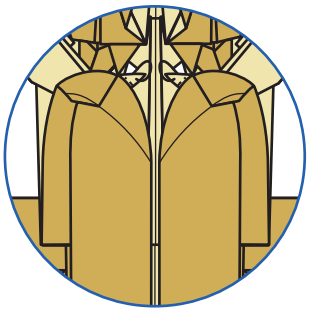
140. Fold a very small amount of paper over, as shown.



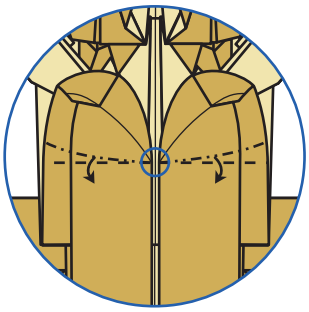
141. Pull the raw corners to the centre. This section of paper won't lie flat from now on.



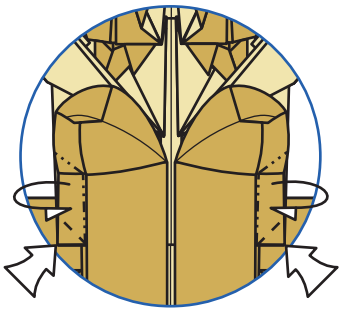
142. Pleat the paper to make the raw corner sharper, as shown.



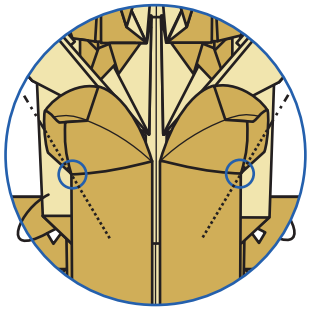
143. Mountain-fold the raw corners behind to lock the folds from the previous step in place.



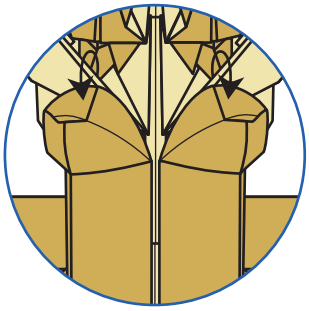
144. Pleat the paper downwards to make the chest rounder by pivoting about the circled point. Curve the mountain fold slightly to achieve this.



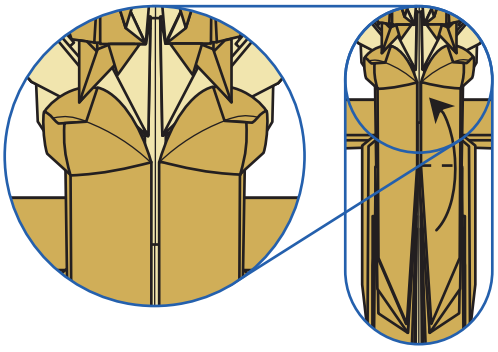
145. Mountain-fold the near raw edge so that it is in front of the white region. You will need to perform a small squash-fold at the bottom on each side.



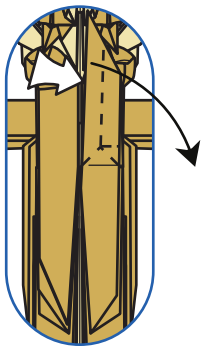
146. Mountain-fold using a fold-line which goes through the circled points.



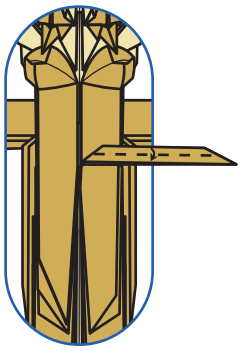
147. Bring the corners to the front.



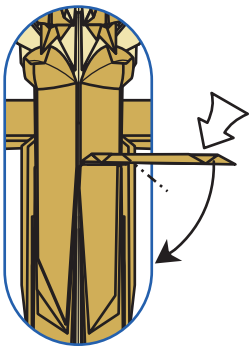
148. Fold one flap up.



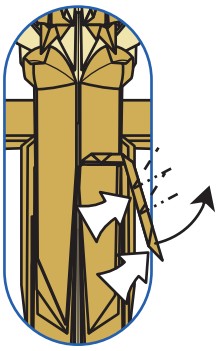
149. Rabbit-ear the flap to the right.



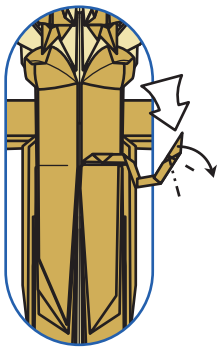
150. Fold the leg in half.



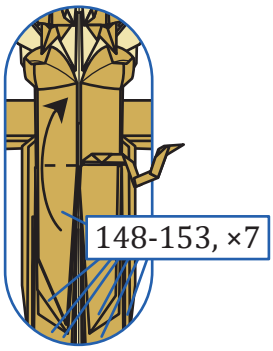
151. Reverse-fold the leg down.



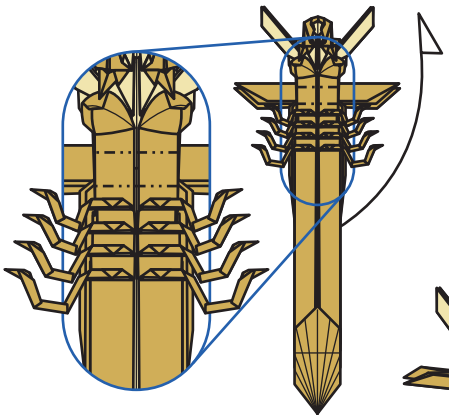
152. Crimp the leg upwards twice.



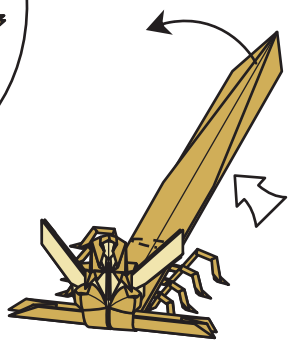
153. Crimp the end of the leg to make a foot.



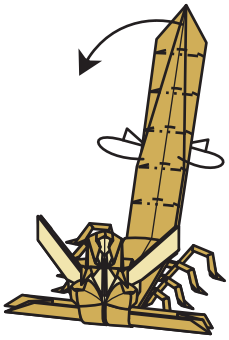
154. Repeat steps 148 to 153 on the other seven legs.



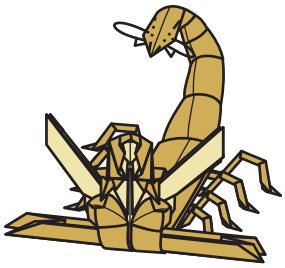
155. Mountain-fold the entire lower region upwards so that it is perpendicular to the torso.



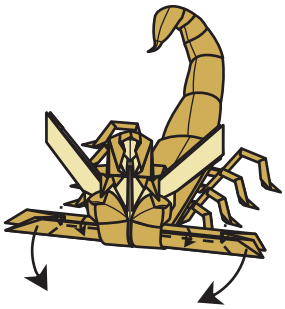
156. Curl the body slightly and crimp the tail so that it becomes vertical.



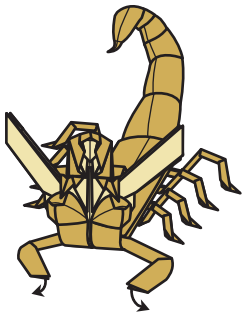
157. Curl the tail with more crimps.



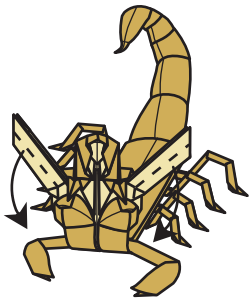
158. Curl and shape the paper at the stinger.



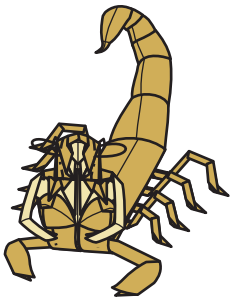
159. Rabbit-ear to fold the claws down while narrowing the inner parts of the flaps.



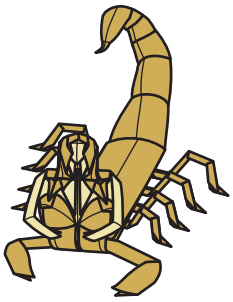
160. Open and shape the claws.



161. Rabbit-ear and shape the arms.



162. Curve the head and torso.



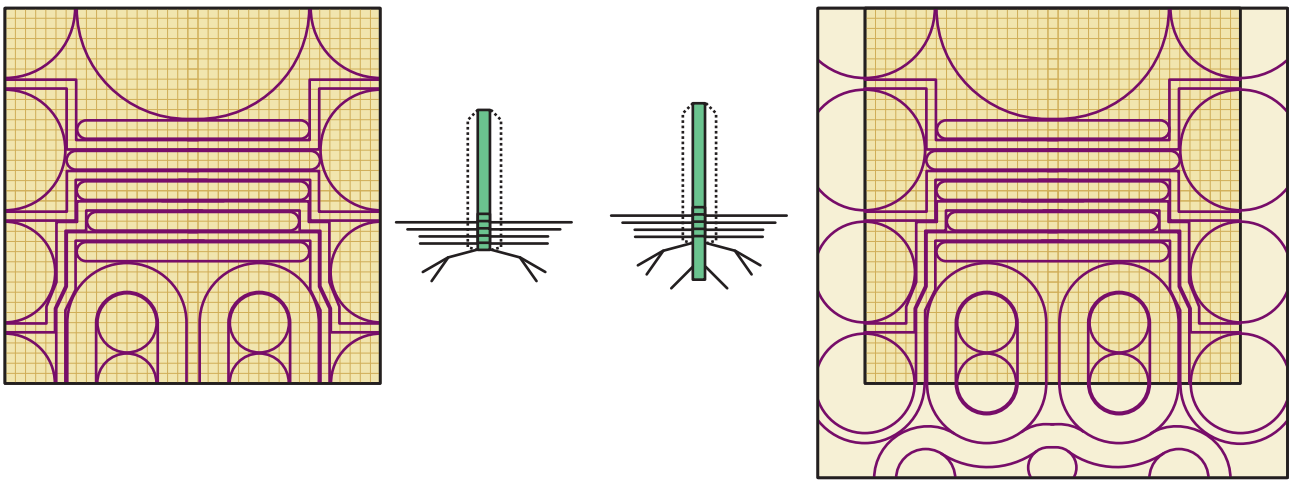
Additivity

Some art forms have the luxury of being additive: you can develop the same piece by adapting and changing individual sections independently. If you didn't like your original pencil sketch, then paint over it; or if you need more material on your sculpture, just splat some more clay on. (I'm sure there's more nuance involved, but as you can presumably tell, I'm neither a painter nor a sculptor.)

Origami doesn't have this benefit. You cannot simply add new features to an existing origami design without affecting the whole model. (Or at least, purist origami isn't additive: you can easily add paper by using another sheet if you wish.) The most sophisticated method for adding onto an origami model is by grafting, but there are several complications with this technique. Grafting:

- Makes existing parts of the original model thicker
- Can affect colour changes
- Alters folding references
- Makes a model less efficient, unless you can use all of the added paper (you almost certainly can't)

It's this last point that is the nail in the coffin for many potential grafting opportunities: grafting is good for adding small details in multiple different places, but not for adding a large flap or set of flaps in just one place. Let's demonstrate this by trying to add the top half of a human to the Scorpion to create an Aqrabuamelu (think a mermaid, but scorpion instead of fish). If we graft new paper to the bottom raw edge, we end up adding at least as much new paper in places where we don't want it. Some of this new paper might be salvageable, but the majority is unusable. And this is being very stringent with the amount of new paper added: the graft below is only enough to create a rudimentary set of flaps, but we would prefer to have much more available paper at the bottom raw edge, which would create even more waste at the sides of the square. Other grafting options, such as adding a vertical strip down the centre of the paper, are similarly problematic.



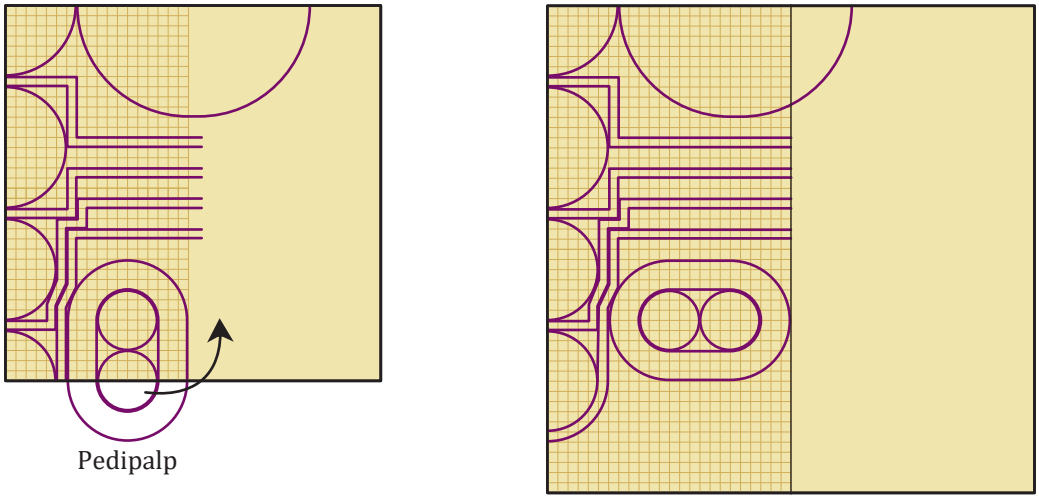
Left: Circle/River arrangement and tree for the Scorpion.
Right: An augmented tree to include a basic human upper half and one possible graft. This requires 56% more paper, and most of this new paper is unusable.

So do you have to start from scratch every time you make a new design, even with very similar models? No, we just have to be a little less direct than a standard graft. Instead, we can borrow patterns and principles to hugely hasten our initial stages of design. We'll see how this can be done to make a more efficient Aqrabuamelu than the one above.

Stealing from yourself

So what ideas can we take from the existing Scorpion design? We started with the leg structure and decided it would be appropriate to use box pleating. Meanwhile, the tergites and the small vertical strip graft were the last things we added (because they filled some remaining space) so let's remove those. As usual, we'll be making a symmetric design, so let's make things easy and just work on one half of the paper for now.

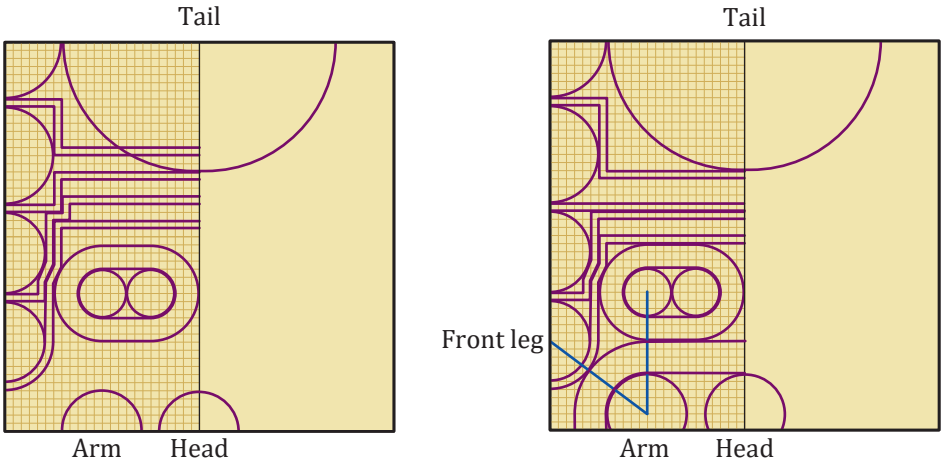
We'll need to make the square wider to accommodate more flaps, and we also need to make more space near the middle of the bottom raw edge for the human torso. We can use a little trick to address both of these observations: let's rotate the pedipalp and use that to define where the line of symmetry should be.



Left: Circle/River arrangement for the left half of the Scorpion.
Right: Rotating the two circles and surrounding river for the pedipalps gives plenty of space at the bottom of the paper.

After making the paper wider, the tail flap is no longer in the centre, so we can expand this circle to fill the space: the square is 6 units wider, so the tail will be 6 units longer. This enlarged circle intersects some of the flaps previously taken up by the tergites and the rivers along the back, so we'll move those flaps down until there are no overlaps.

As for the paper in the new region allotted for the human features, let's fill this space with some initial circles for the arm and head. These have to be separated from the existing rivers and circles to account for the midriff. There's a perfect Pythagorean stretch available if we place the centre of the arm 2 units from the raw edge directly below the left claw – this point is exactly 15 units from the claw and the front leg.



Left: The tail circle has been expanded, and there are new flaps for the human torso.
Right: We tidy up the rivers in the middle of the paper and find a nice alignment for the arm.

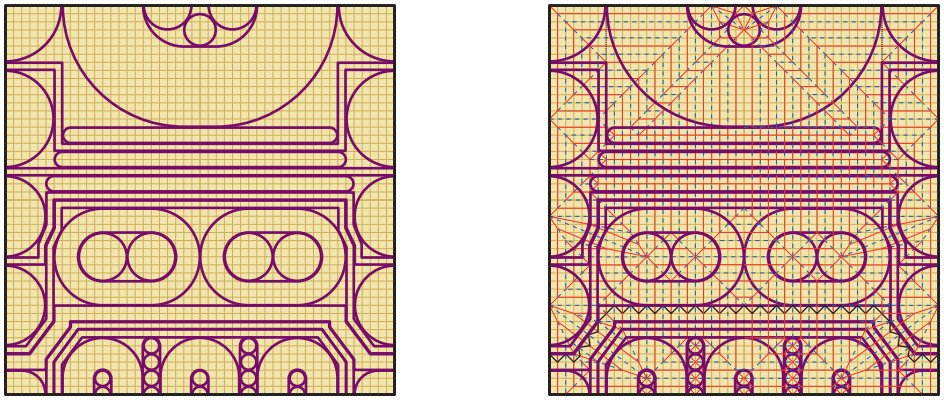
It feels like we're getting close, and this hasn't taken much work at all; we're simply reaping the benefits of having stolen from a previous design. But there are a few problems to fix and extra details to fill in before we're done.

Firstly, there's a small amount of paper at the raw corner which is begging to be used. This paper will be about chest height and can be used for extra detail. Normally clothing would be the first thing to come to mind, but it might look a little strange for this hybrid creature to be wearing typical clothes. Maybe we could use this to make a female Aqrabuamelu … less naked?

Then there's the paper around the head – it doesn't hurt to have a large flap when making origami heads; we can use this paper for long hair, or divide it up into smaller flaps to be used for facial features. It's at the raw edge, and it seems a shame not to make the most of the available colour change, so let's make some hair.

The final problem relates to parity again: there are an odd number of units available for tergites. With a little creativity, we can make a strange split at the tail to make a trident stinger and squeeze one unit out of this flap from another Pythagorean stretch. Here's the creative license when folding fantasy creatures working to our advantage again.

With these three changes we can complete the crease pattern – this is shown bel…



Left: The circle/river arrangement for the Aqrabuamelu.
Right: Full crease pattern?

Hang on, this isn't the crease pattern shown on page 123 and if you've already folded the model, you'll know that this doesn't match the diagrams. What's going on?

Pragmatism and complication

The crease pattern above is the original design I came up with when designing this model in tandem with the Scorpion. I made diagrams for the Scorpion and fully intended to make diagrams for the Aqrabuamelu too. But the design stayed like this for about six months, and in that time I never had the inclination to fold it, let alone make diagrams for it. There's nothing incorrect about the arrangement, and it's a perfectly valid crease pattern, so why didn't I want to fold it?

There are several reasons, and note that these are all subjective concerns:

- The model is rather inorganic ("boxiness" is the inevitable result of box pleating).
- The design has become disproportionately tricky. Even though there are only a small number of extra flaps compared to the scorpion, the number of internal flaps has doubled. To achieve a colour change where the creature's scorpion half meets the human torso, there is a very nasty mixed-reverse-fold – this is the jagged line in the crease pattern.
- I have little patience for folding large grids.
- The idea of diagramming the collapses needed to make the base is unpleasantry at its most pronounced. I can only make diagrams for a finite number of models in my lifetime, and I have to be realistic about whether it's really worth it. This may not seem like a design issue, but experience warns me that if I don't want to make the diagrams, people aren't going to want to fold the model.

In the effort of making this model efficiently and efficient, I'd overcomplicated it by falling into the greatest sin of origami design (yes, even more than cuts): making the design process easy at the expense of folding difficulty. (Or at least that's my opinion – perhaps some people wouldn't mind folding the above crease pattern. Please do give it a go; you'll have beaten me to folding my own model.)

Don't mistake what I'm saying here: I like complex models. But the design for the Aqrabuamelu above isn't just complex, it's *complicated*. I think it's helpful to distinguish between the models that are complex out of necessity to create the designer's vision of the subject, rather than because the designer hasn't taken the time to clean up their model (and of course, I am primarily critiquing myself in this regard). The design process isn't over just because the model is efficient and satisfies the flap requirements of the tree. The final design stage is to simplify the model by pruning away the problems until a healthier model emerges.

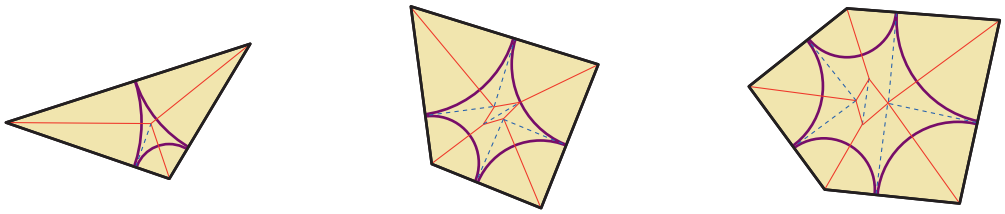
New life

This cleaning-up process occurs incrementally in many designs, but I've chosen to discuss it in this chapter because, for this model, we happen to be able to do something unusually dramatic using a method that can (and should) be reused elsewhere.

Deboxing

Our problems stem from box pleating. Recall how right back at the beginning of the Scorpion design, we used this to make things simple. But simplicity needs to be qualified: simpler for whom? Box pleating was a design shortcut to get features in roughly the right places on the square, but I never indicated (or even suggested that we should consider) if this was simpler for the person folding the model!

We'll seek to remedy this past mistake by removing the box-pleated creases and instead using a circle-packed design geometry – I'll call this process **deboxing**. We'll add new axial creases between close pairs of circles to create polygons whose edges are all axial lines. Such polygons are called **molecules**. Molecules are self-contained and are easy to fold when the number of edges of the molecule is small: three sides is easy, four can be fine, but five or more should generally be avoided.

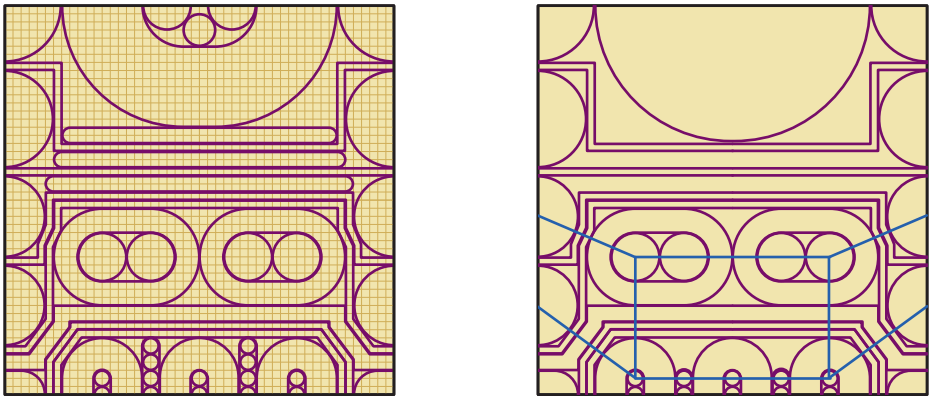


Examples of molecules with three, four, and five sides.

But can we debox the first Aqrabuamelu crease pattern without losing the arrangement that we've worked so hard to achieve? Well, mostly; there will be sacrifices, but I hope you'll agree the final result is worth it.

The main bonuses box pleating provides are actually the very last things we added: the tergites and some of the small flaps around the shoulders (we can keep the horizontally-aligned flaps near the bottom raw edge because this bottom strip looks like it could be a graft, which should be easy to fold). From a design perspective, these small unit-length flaps slot in easily when box pleating, but are hard to replicate with molecules. (Or at least, they are hard to replicate with simple-to-fold molecules: you can make a monstrous molecule that copies the tergites from the box-pleated arrangement perfectly, but then we have only made the problem worse!)

But these tergites are some of the trickiest parts of the Aqrabuamelu to fold, so we should not lament losing them; prioritising ease of folding is the whole point of deboxing. Let's also remove the grid and the point split at the tail. (Notice how we are removing features in roughly reverse order – this indicates that the initial circles which we are keeping never relied upon box pleating to begin with.) Then we'll draw in the axial creases for the remaining flaps.

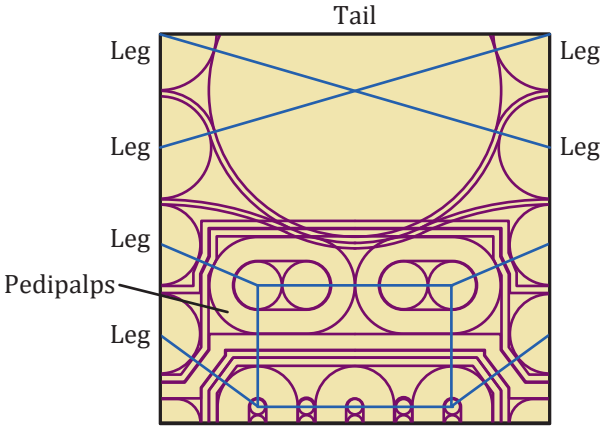


Left: The box-pleated Aqrabuamelu's circle/river arrangement.
Right: The grid and some small flaps have been removed, and axial creases have been drawn on.
Note that the entire raw edge is axial.

The large polygons without any axial creases will not be possible to fold using simple molecules, so we need to add more axial creases to break them up. There are two ways to do this:

- Add more small flaps in the empty space between circles or rivers. This lets us keep the same arrangement, but adding more flaps is a terrible idea if we want to make the model simpler.
- Move the existing flaps until they touch. We may also need to adjust their sizes to maintain existing axial connections. This is the method we'll use, but the skill is in keeping both types of adjustments to a controlled level so that we don't disrupt the tree in a significant way.

As usual, it makes sense to consider large flaps first. We'll start by moving the tail flap down so that we get new axial creases that connect the tail to the second pair of legs from the top (we have room to do this because we no longer have the tergites). The best location is to make the circle's centre exactly in the middle of the four legs at the top, because this creates an X shape with axial creases; we will only need to fold twice to make four axial lines. We'll need to expand the circle slightly to fill the space (see if you can work out how long this new flap is, and find another reason why I'm particularly pleased with this circle's new location).

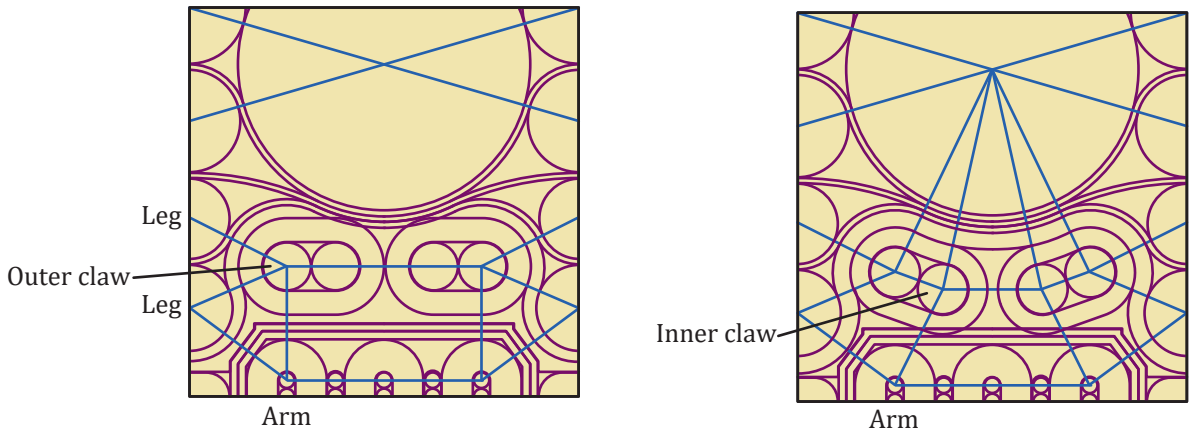


The tail has been moved down and expanded slightly. This creates four new axial creases. Even though this may look inefficient, there are some practical benefits to having a (partially) internal flap, such as hiding the raw edge on the stinger.

The circle now overlaps with the pedipalps, so we should move them down. In fact, looking at the axial creases, we can see something strange: the outer claws are closer to the third pair of legs from the top in the arrangement, but they should be closer to the lowest pair of legs in the final model. So this movement yields a more natural arrangement for multiple reasons. As before, this adjustment will force us to make some small changes to the flap lengths.

But the inner and outer claws are at slightly different distances from the tail. To rectify this, we rotate the pedipalps so that they are no longer horizontal. This gives another four axial creases. In moving the claws,

we've made the arm closer to the inner claw than the outer claw, so we have to change the axial crease, as shown below. Additionally, the inner claws no longer touch. This would normally be a problem, but at the centre of the paper, we actually want more distance here to separate the left and right halves of the model, so this line is counted as axial. (In the diagrams, this distance is treated as axial too – an approximation that enforces a small amount of three-dimensionality, and would be unnoticed by most folders.)



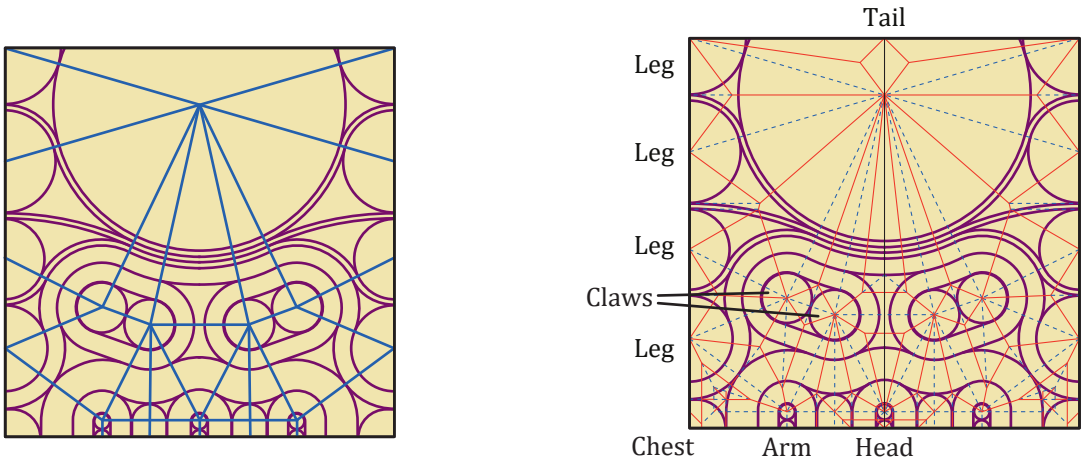
Moving and rotating the pedipalps provides four more axial creases.

We have just one remaining molecule with more than four sides (at the bottom of the paper on the right image above), so let's add some more axial creases to break it up. Once again, this will adjust the flap lengths a little. As mentioned earlier, if we fold the raw edge over early in the folding sequence, we can treat this as a graft and use it to get a colour change for the human skin. Border grafting like this means we can treat the folded edge as a new 'raw edge', which is useful because axial creases that terminate at the raw edge can be folded easily with squash folds and petal folds, much like the points in a frog base (see steps 100 and 101 on page 138). This gives the final circle-packed crease pattern below.

Conclusion

This design is much easier to fold than the box-pleated version, but was it worth this extra hassle? An overwhelming "yes" from me, but the test is to have a go yourself: fold both and see which you prefer.

That may not seem like a fair comparison because I've only provided diagrams for the circle-packed version. But diagrams don't spring out of nowhere – sequences have to be found, and this is exactly my point: there is no nice sequence to fold the box-pleated version. This is a direct consequence of the design process and therefore a property of the model itself. So here's the real test: in general, have you ever been dissuaded from folding a model because you only had its crease pattern rather than step-by-step diagrams? I suspect the answer is "yes" from every folder.



Left: All molecules now have only 3 or 4 sides; all axial creases are now filled in (as valleys).
Right: The final crease pattern.

Spider

First time: 50cm/20''

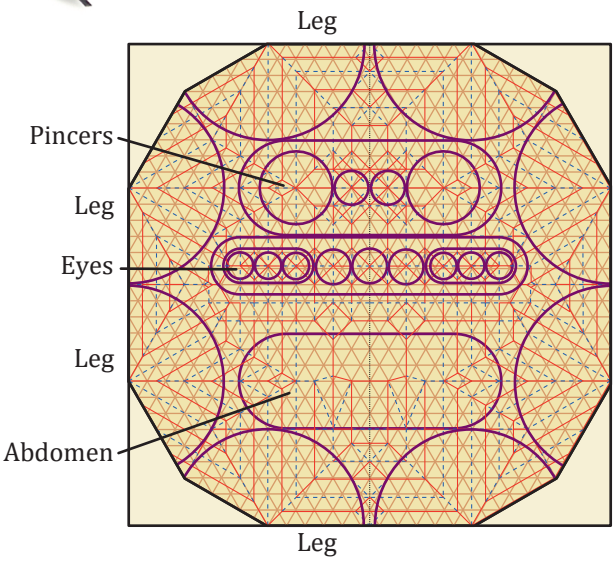
Paper preferences:
- Thin
- Shapeable
- Tearproof

Recommended papers:
- Single tissue
- Origamido

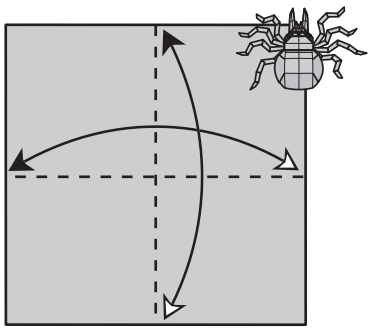
Many fantasy worlds contain spiders, whether as a potion ingredient, a gigantic foe, or spooky ambience.

This design isn't intended to accurately depict any particular species, but is a generic spider. Display it with other models in a scene to give it some context!

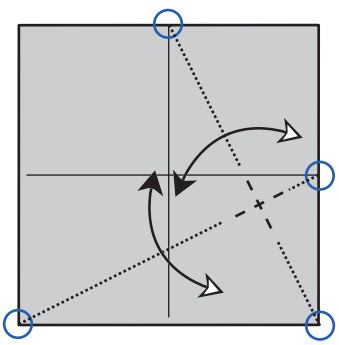
Although the step count isn't that high (for complex origami), steps 73 to 83 are very challenging and earn this model supercomplex status. Well done when you make it through that page!



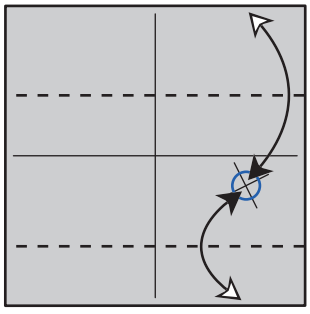
Start body colour side up.



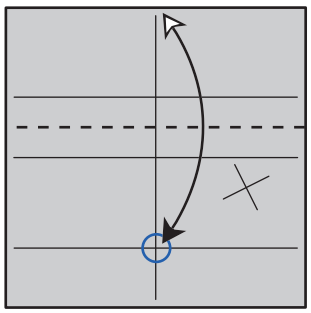
1. Fold and unfold the central vertical and horizontal lines.



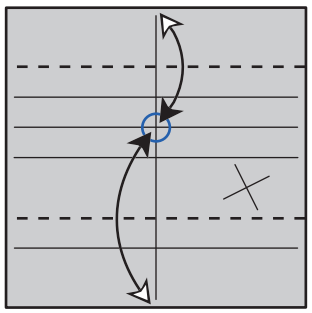
2. Fold and unfold two fold-lines which connect the intersections shown, marking firmly only where they overlap.



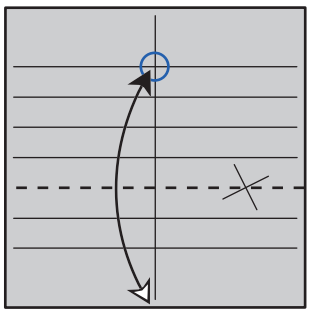
3. Fold the top and bottom raw edges to the circled point, then unfold.



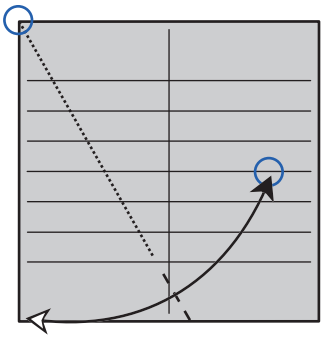
4. Fold the top raw edge to the lowest crease, then unfold.



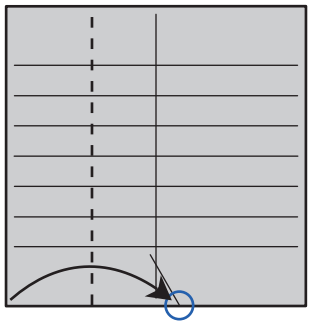
5. Fold the top and bottom raw edges to the crease you just made, then unfold.



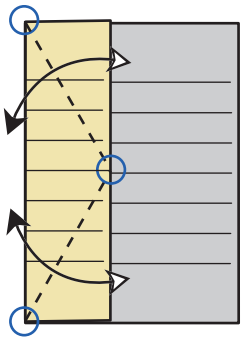
6. Fold the bottom raw edge to the indicated crease, then unfold. Creases from step 2 will no longer be shown.



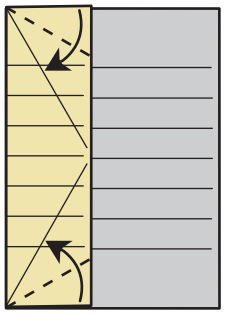
7. Bring the bottom-left raw corner to the middle crease using a fold-line that starts at the top-left raw corner. Mark firmly only at the bottom raw edge, then unfold.



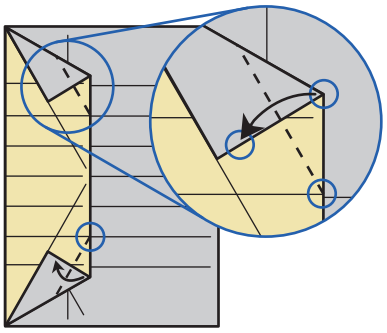
8. Fold the bottom-left raw corner to the mark you just made.



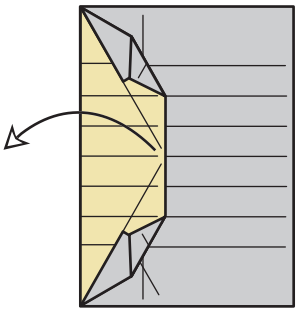
9. Fold the raw corners to the left, then unfold. The fold-lines connect the circled intersections.



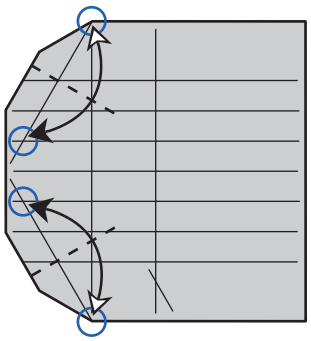
10. Fold the raw edges to the creases you just made, as shown.



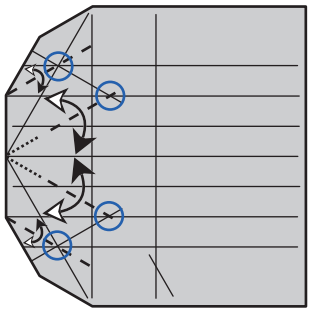
11. Fold the corners so that they lie on the raw edge, using fold-lines which start at the horizontal creases shown.



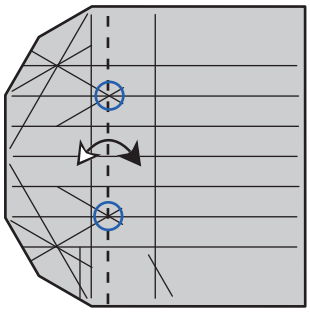
12. Unfold step 8.



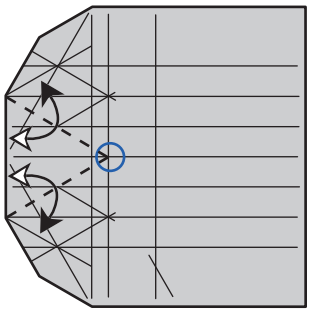
13. Fold the circled points together and unfold.



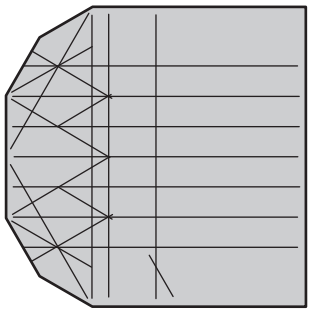
14. Fold and unfold four angle bisectors. The fold-lines should also go through the circled points.



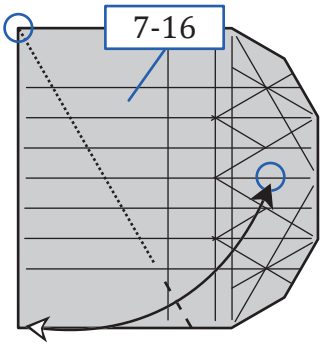
15. Fold and unfold a vertical line through the circled points.



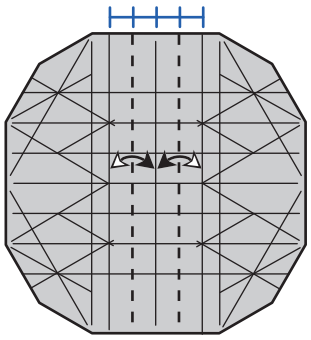
16. Fold and unfold two angle bisectors. Ensure the fold-lines also go through the circled point.



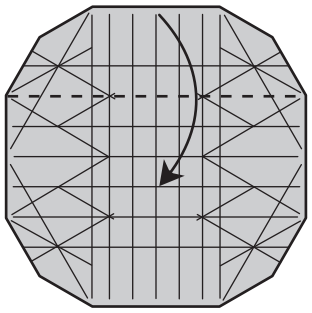
17. Rotate the paper ½ a turn. Some creases will no longer be shown.



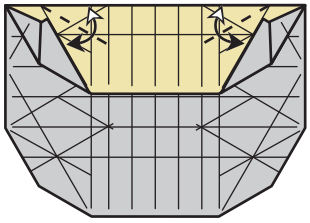
18. Repeat steps 7 to 16.



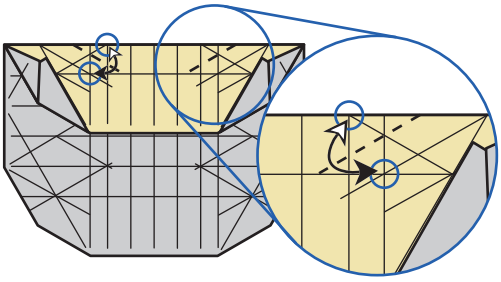
19. Fold and unfold two vertical lines halfway between existing creases.



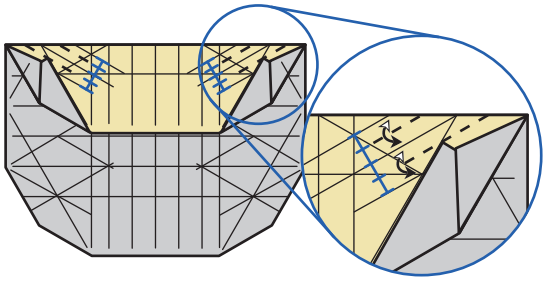
20. Fold the top section down using an existing crease.



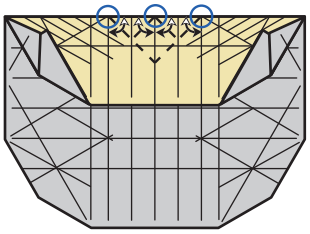
21. Fold two angle bisectors and unfold.



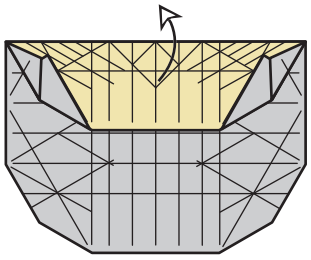
22. Fold the circled intersections together and unfold.



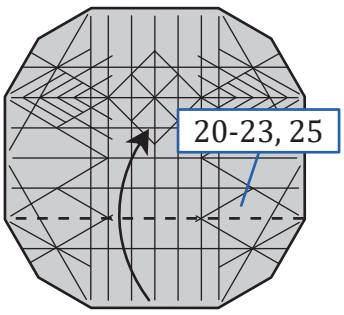
23. Fold four pairs of creases together and unfold.



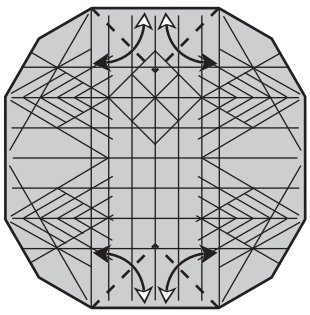
24. Fold and unfold four angle bisectors.



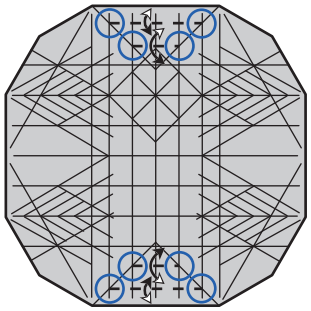
25. Unfold step 20.



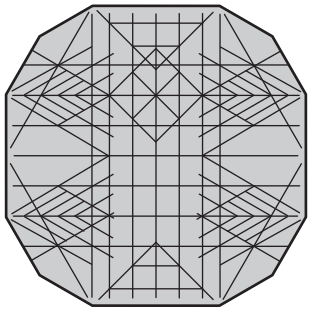
26. Repeat steps 20 to 23 and step 25 on the bottom. This is easiest if you rotate the paper half a turn (but remember to turn it back again).



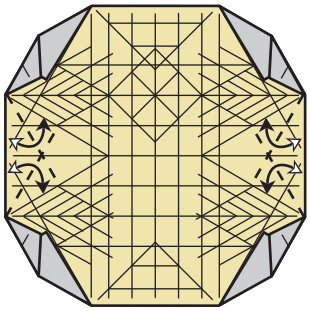
27. Fold and unfold four angle bisectors.



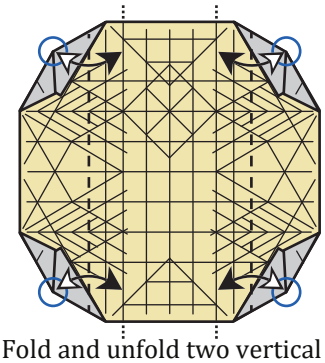
28. Fold and unfold four horizontal fold-lines through the circled points.



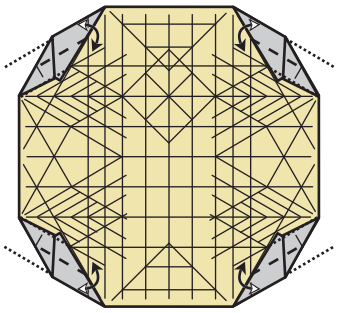
29. Turn the paper over.



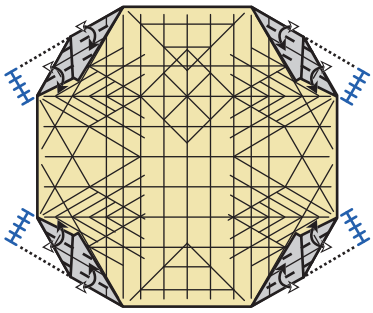
30. Fold and unfold four angle bisectors.



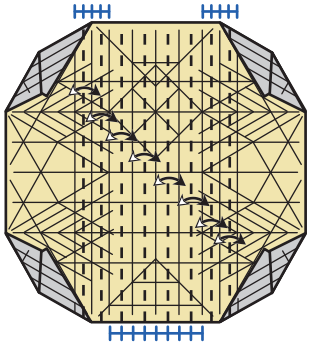
31. Fold and unfold two vertical lines by bringing the circled corners to the creases made in step 15.



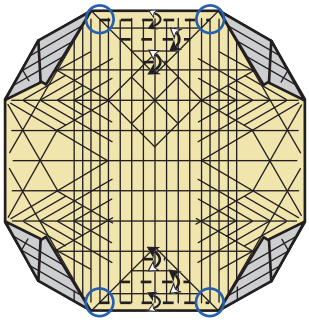
32. Fold and unfold four pairs of lines together.



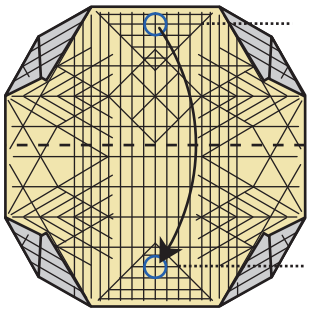
33. Fold and unfold eight pairs of lines together.



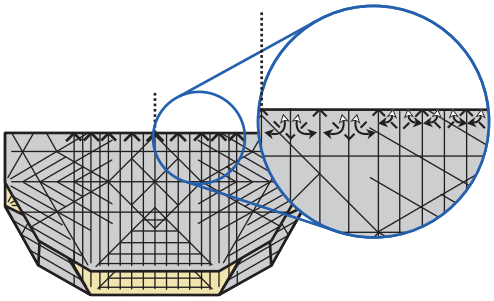
34. Fold and unfold eight pairs of creases together. Note that these are not all evenly spaced.



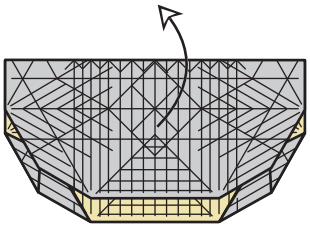
35. Fold and unfold six horizontal lines. Note that these are not all evenly spaced.



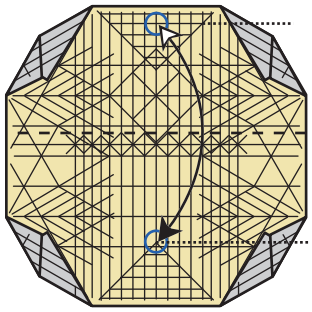
36. Fold the upper circled point to the lower circled point.



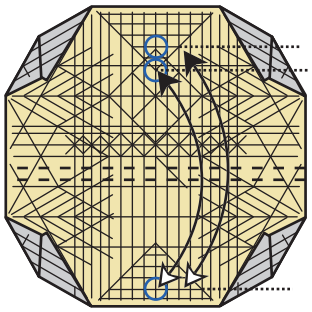
37. Fold eighteen angle bisectors (the dotted line is the central crease).



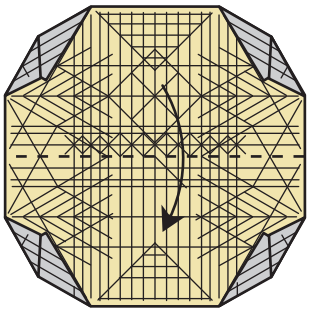
38. Unfold step 36.



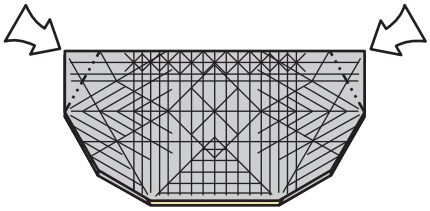
39. Fold the upper circled point to the lower circled point. (The lower circled point is at the top of the creases made in step 27.) Then unfold.



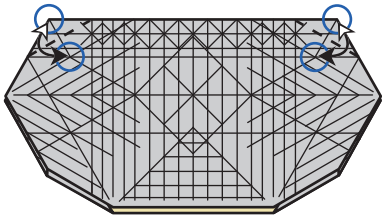
40. Fold and unfold the lower circled point to each of the upper circled points, like steps 36 and 39.



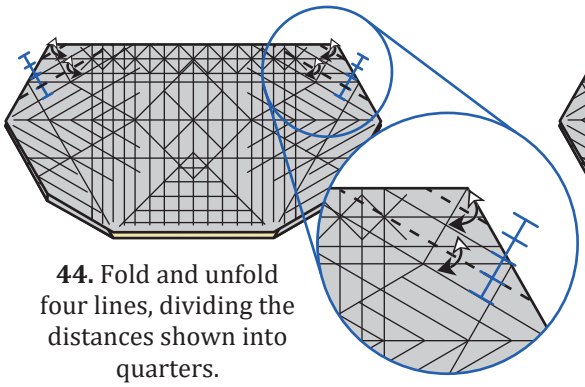
41. Fold the top half on top of the bottom half.



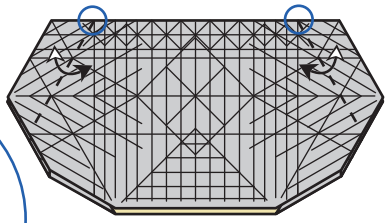
42. Reverse-fold using existing creases.



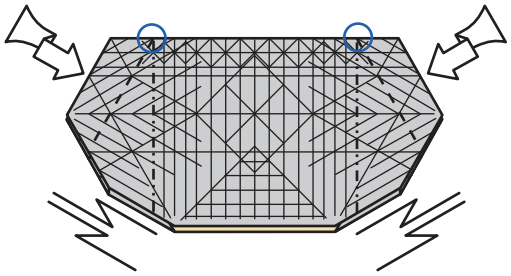
43. Fold the circled points together and unfold.



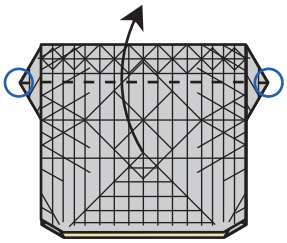
44. Fold and unfold four lines, dividing the distances shown into quarters.



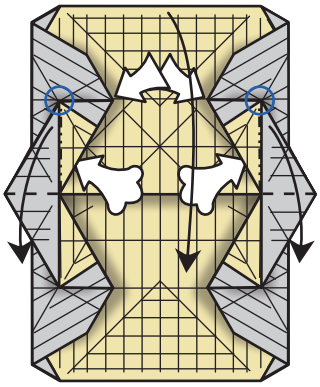
45. Fold and unfold an angle bisector on each side.



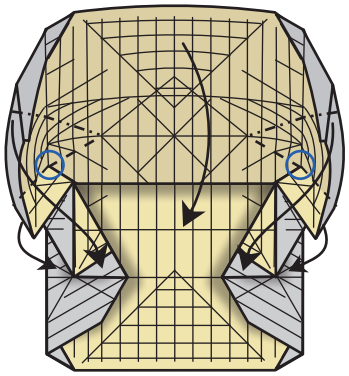
46. Crimp each side in, pivoting about the circled points.



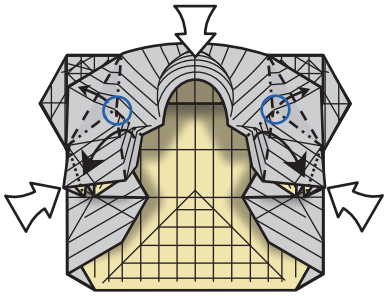
47. Fold the near section upwards.



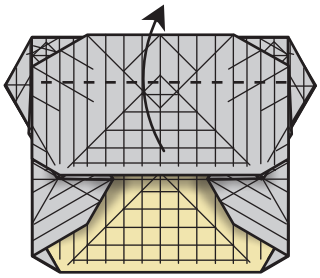
48. Pull the circled corners down, pinching the vertical mountain folds along the raw edges. The top section will come forwards, and won't lie flat until after step 50.



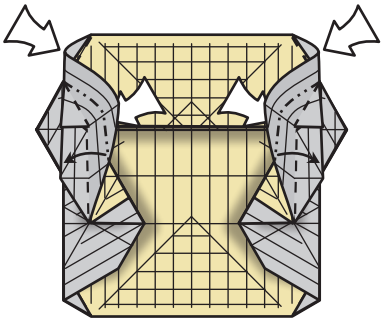
49. Note the circled vertex on each side. Make the valley folds shown through these vertices, and bring the mountain folds down so that they become vertical.



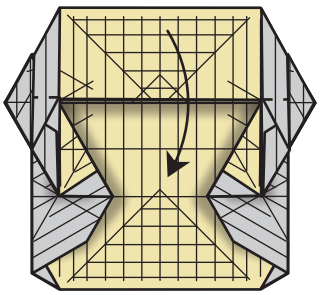
50. Bring the circled corners outwards. The paper should then flatten using existing creases.



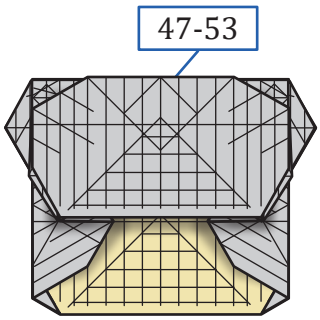
51. Fold the flap up using an existing crease. The paper won't lie flat until after step 52.



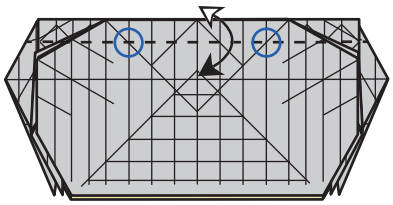
52. Flatten the paper using existing creases, as shown.



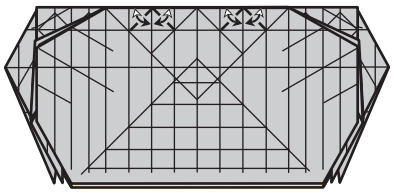
53. Fold the flap down.



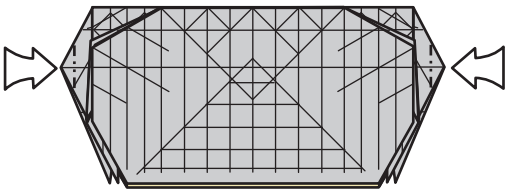
54. Repeat steps 47 to 53 on the back.



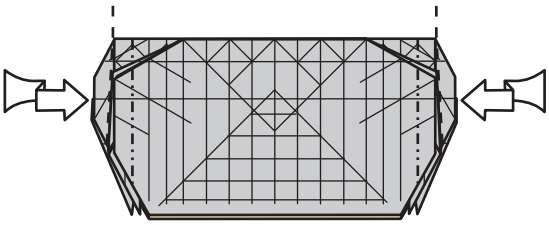
55. Fold and unfold the nearest **two** flaps with a fold-line that passes through the circled intersections. The creases only need to be made at the sides of the second flaps as they already exist in the centre.



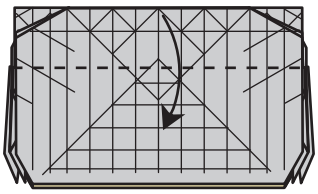
56. Fold and unfold four angle bisectors in the nearest flap only.



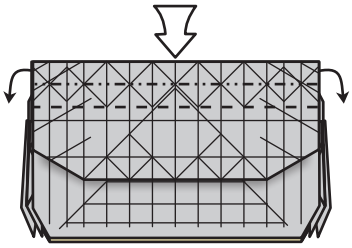
57. Open-sink two small corners using existing lines.



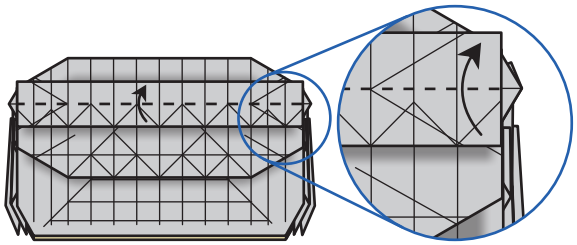
58. Open-sink the entire ridge on the left and right sides. You will need to open the paper significantly to do this. Most of the necessary lines are already precreased. This step could take some time.



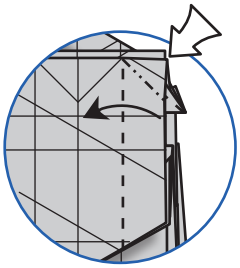
59. Fold the nearest flap down.



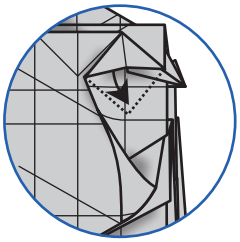
60. Spread-sink the top edge using mostly existing creases. Don't unfold the pleats made in step 58, but flatten a hidden corner on the central edge under the pleat on each side.



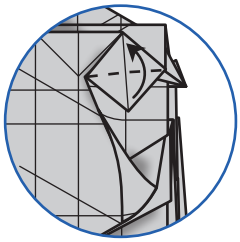
61. Fold one flap back up.



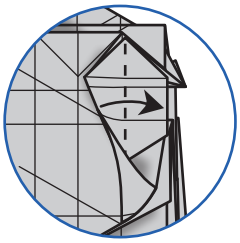
62. Fold one edge to the left and squash-fold the corner. The paper at the bottom won't lie flat until after step 65.



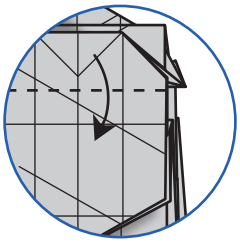
63. Unsink the corner. Be careful – it's very easy to tear the paper here!



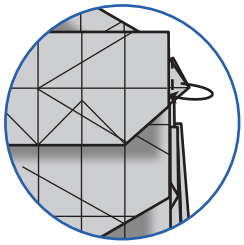
64. Fold the corner back up.



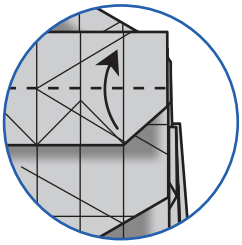
65. Fold the edge back to the right to flatten the paper.



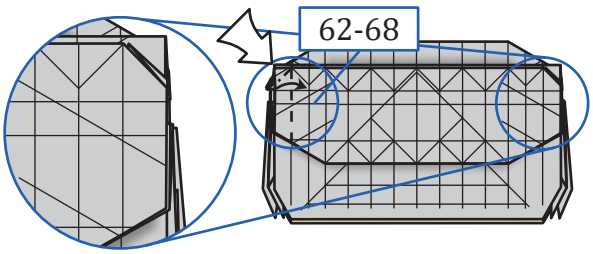
66. Fold one flap down.



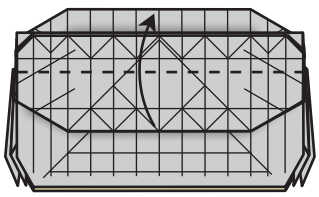
67. Valley-fold the corner under the edge so that it no longer sticks out.



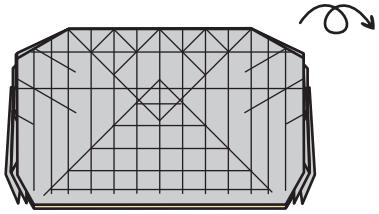
68. Fold the flap up.



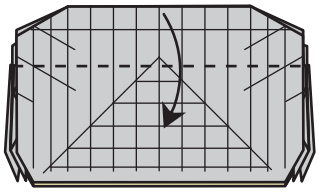
69. Repeat steps 62 to 68 on the left.



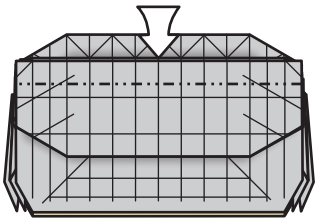
70. Fold one flap up.



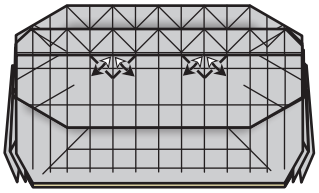
71. Turn the paper over.



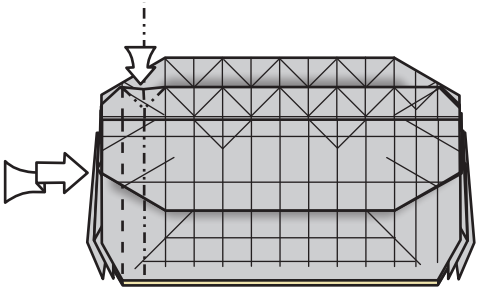
72. Fold the nearest flap down.



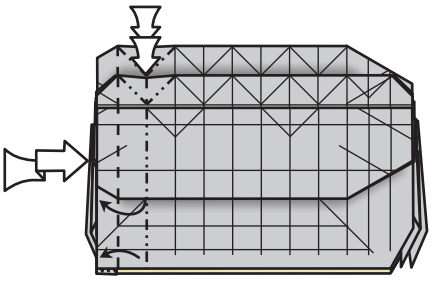
73. Closed-sink one edge inside. It needs to go between the nearest possible layers.



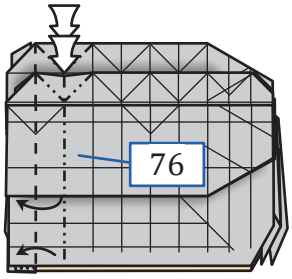
74. Fold and unfold four angle bisectors in the nearest flap.



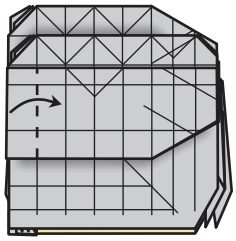
75. Sink the left side in and out using mostly existing creases. The sink is open at the slanted edges, closed at the edge made in step 73, and contains a small collapse along the second edge from the top.



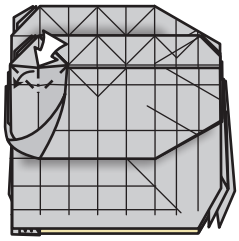
76. Sink in and out using existing creases: collapse on the top and second edges, closed-sink at the edge made in step 73, and wrap the mountain fold around to the left on the second edge from the bottom.



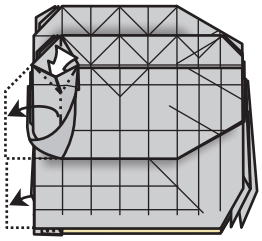
77. Repeat step 76 with the next pair of vertical edges.



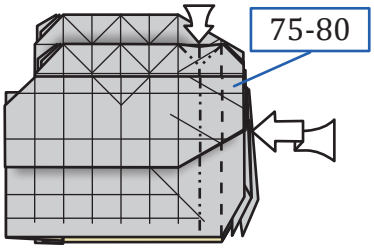
78. Fold one edge to the right. The paper won't lie flat until after step 80.



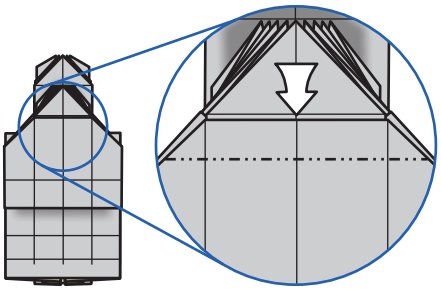
79. Reverse-fold the edge down to the left using creases made in step 74.



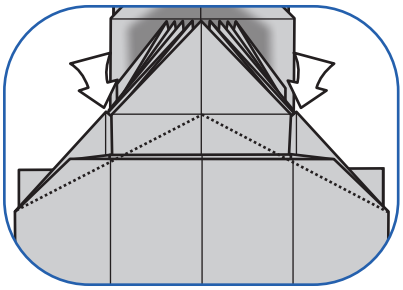
80. Unsink the edge to the left and flatten the paper. You will need to unfold the near portion of the paper to achieve this.



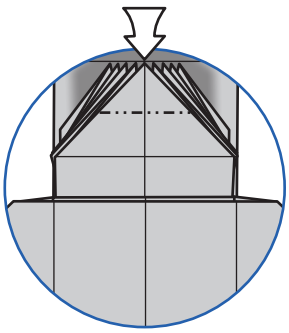
81. Repeat steps 75 to 80 on the right.



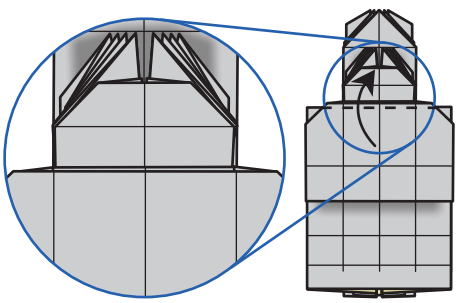
82. Open-sink the horizontal edge. This is a little tricky, since this edge wraps around a vertical folded edge.



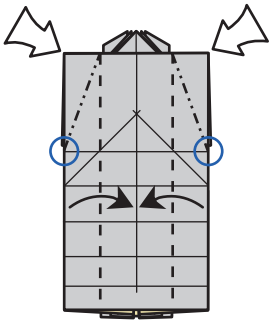
83. Open-sink the small corners diagonally. This is also a little tricky, for the same reason as with step 82.



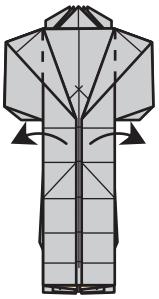
84. Open-sink the central point.



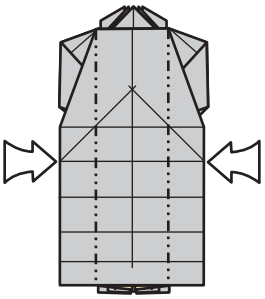
85. Fold the nearest flap up.



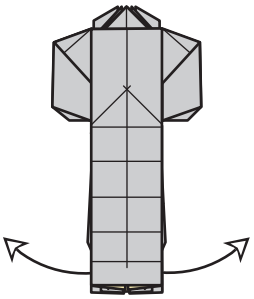
86. Swivel-fold the edges into the centre, making new mountain folds, as shown.



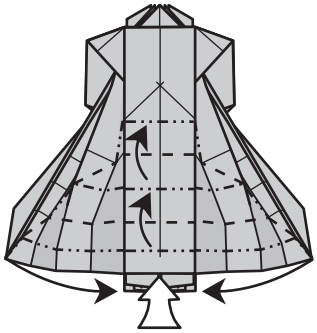
87. Fold the edges out to the sides.



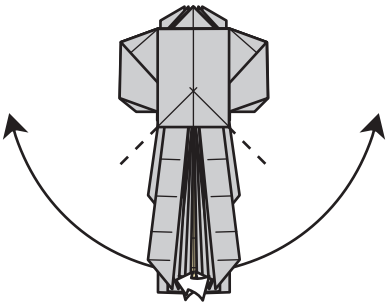
88. Closed-sink the edges.



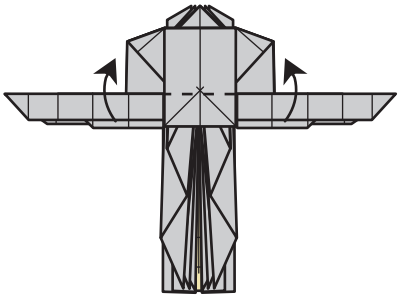
89. Open the pleats at the bottom so that you can see the whole horizontal raw edge. The paper won't lie flat until after step 90.



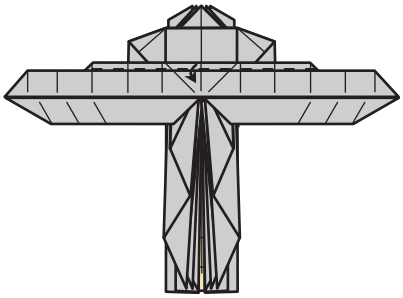
90. Box-stretch using existing creases and flatten the paper.



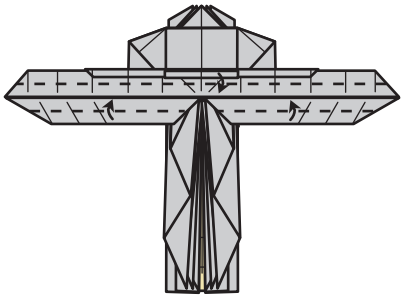
91. Reverse-fold the two nearest flaps to the side.



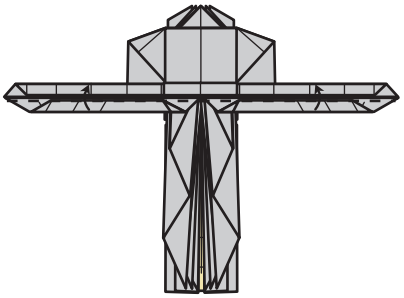
92. Fold the near edge up.



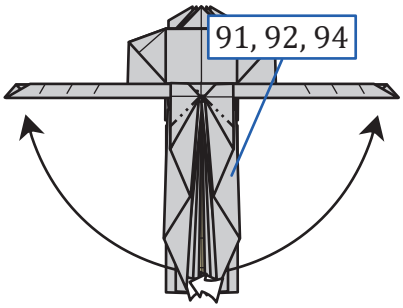
93. Fold the narrow edge down.



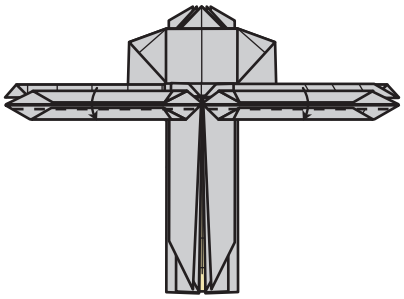
94. Fold the edges to the centre.



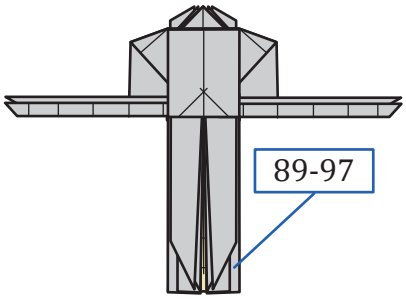
95. Fold the narrow edges upwards.



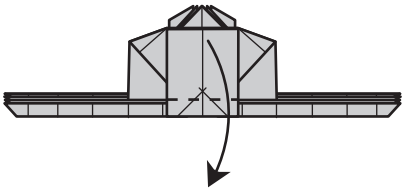
96. Repeat steps 91, 92, and 94 on the next pair of flaps.



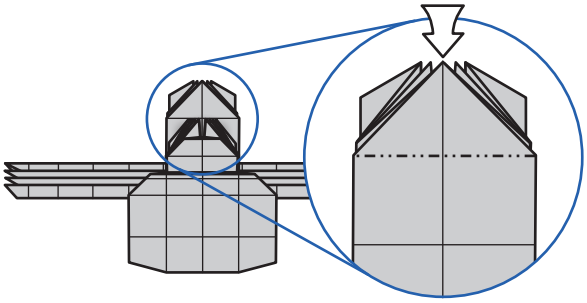
97. Fold all of the thin edges down.



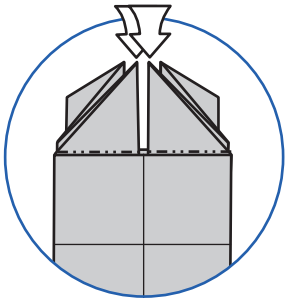
98. Repeat steps 89 to 97 behind.



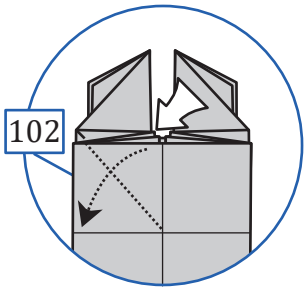
99. Fold one flap down.



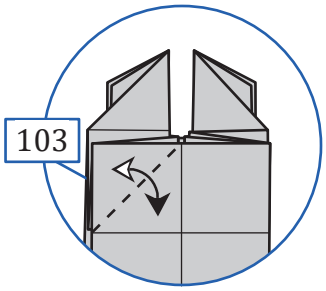
100. Only the some of the layers will be shown for steps 100 to 108. Open-sink the corner.



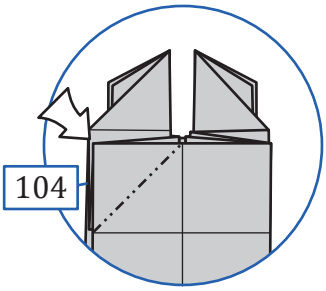
101. Open-sink the two inner corners.



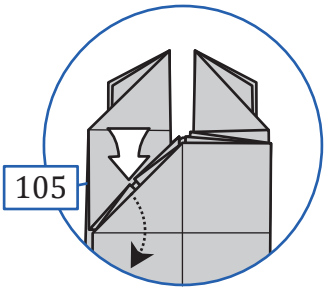
102. Reverse-fold one edge. Repeat behind.



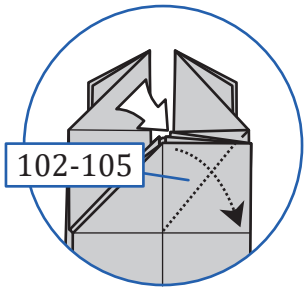
103. Fold and unfold. Repeat behind.



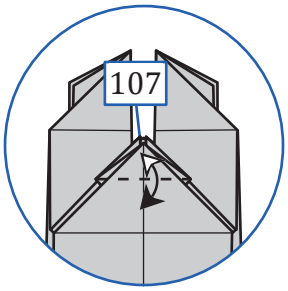
104. Open-sink. Repeat behind.



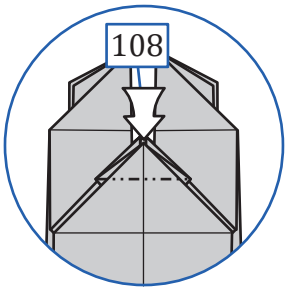
105. Reverse-fold the corner down. Repeat behind.



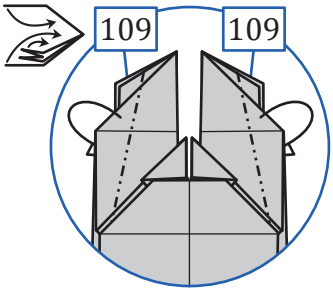
106. Repeat steps 102 to 105 on the right.



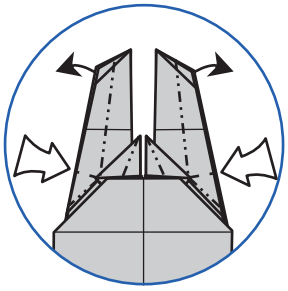
107. Fold and unfold. Repeat behind.



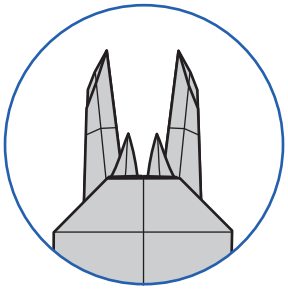
108. Open-sink. Repeat behind.

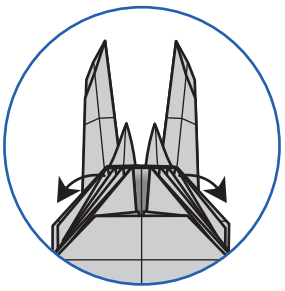


109. Mountain-fold two edges under on the front, and one edge on the back.

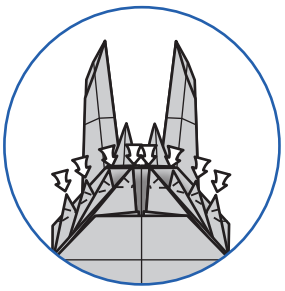


110. Pinch four flaps in half with rabbit-ears to form pincers.

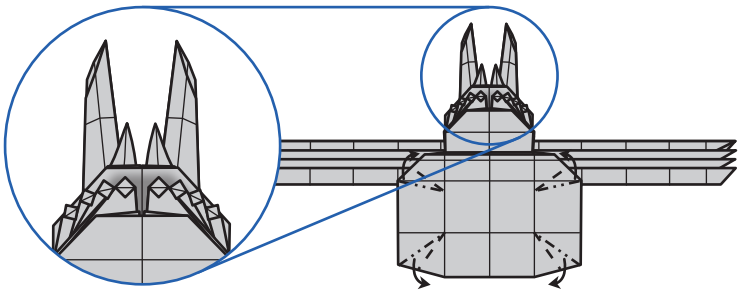




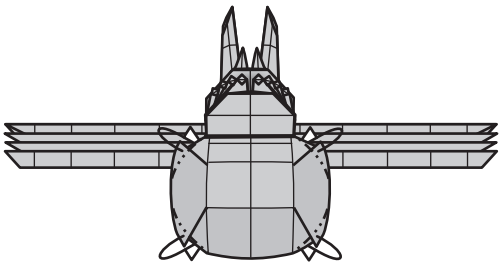
111. All layers are now shown. Spread the corners evenly.



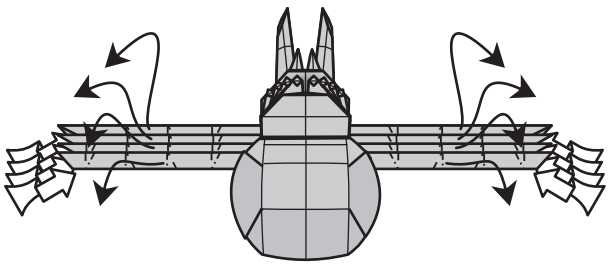
112. Squash-fold each corner to make eight eyes.



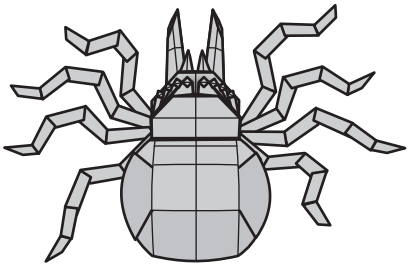
113. Pinch the corners of the abdomen to make it three-dimensional.



114. Mountain-fold the corners underneath to lock the shape in place.



115. Shape each leg using multiple crimps.



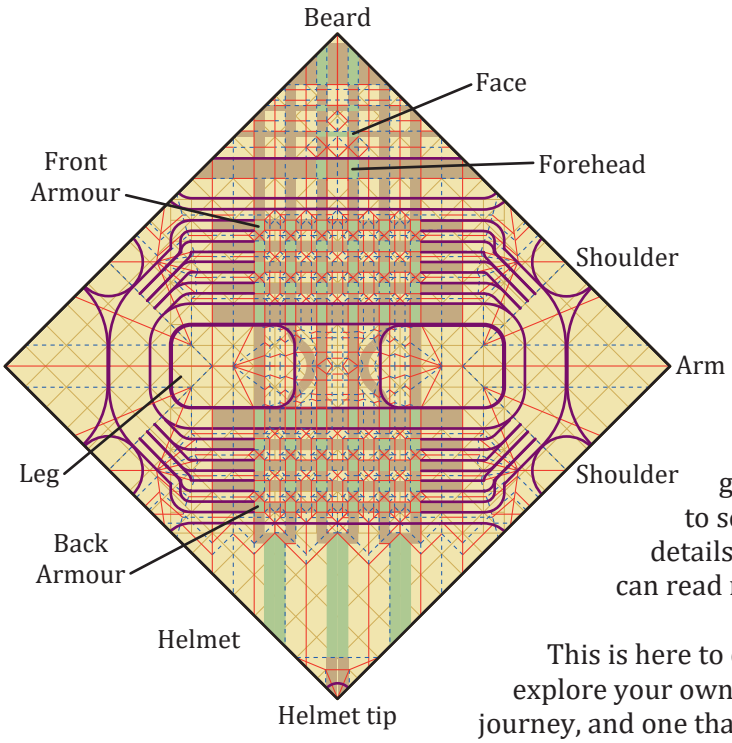
Dwarf Brawler

Folded and photographed by Michael Nguyễn

First time: 50cm/20''

Paper preferences:
- Duo
- Shapeable
- Tearproof

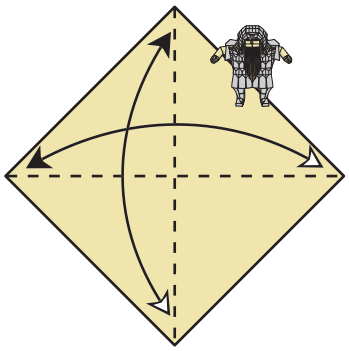
Recommended papers:
- Foil-backed paper
- Double tissue



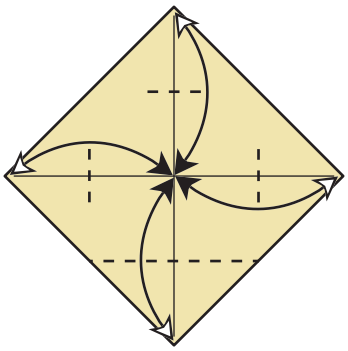
The Dwarf Brawler is already a brutally difficult design in many ways, but Michael's stunning rendition is here to give you an even greater challenge. He's found enough extra paper to sculpt fingers, a more realistic face, and several details on the helmet, including horns and a bird! You can read more about Michael and his work on page 182.

This is here to encourage you to push beyond the diagrams and explore your own unique variations as you fold. But this is a long journey, and one that I'm still working on! A photo of my own, more rigid interpretation of the Dwarf Brawler can be seen on page vi.

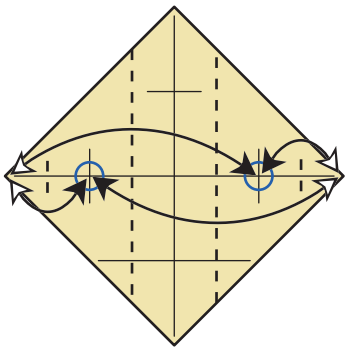
Start skin/beard colour side up.



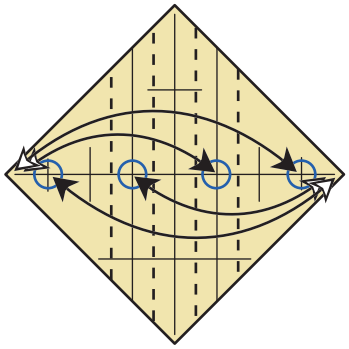
1. Fold and unfold the diagonals.



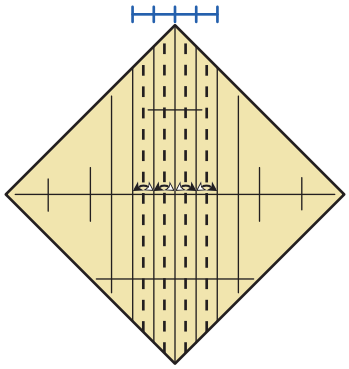
2. Fold the raw corners to the centre, but only mark the upper three fold-lines firmly where they cross the diagonals, then unfold.



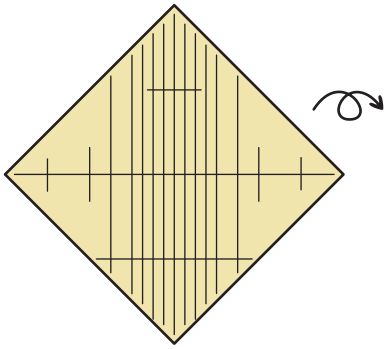
3. Fold the left and right raw corners to the circled points, marking firmly only where shown.



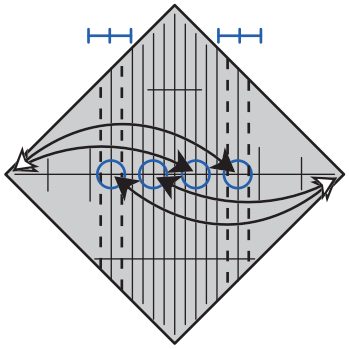
4. Fold and unfold the left and right raw corners to the creases you just made.



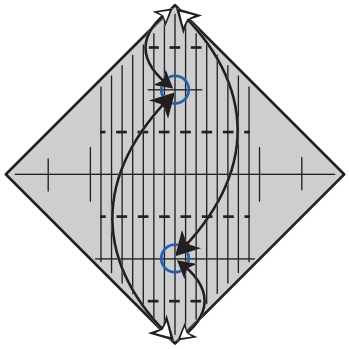
5. Fold and unfold halfway between four pairs of creases.



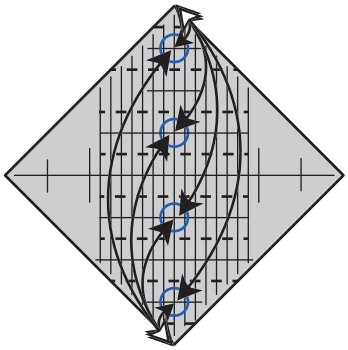
6. Turn the paper over.



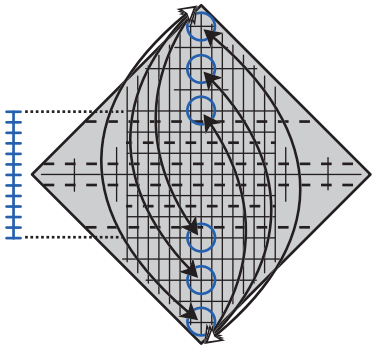
7. Fold and unfold the left and right raw corners to the circled points.



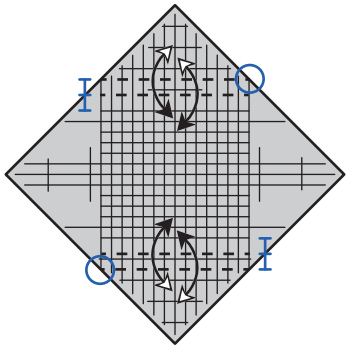
8. Fold and unfold the top and bottom raw corners to the circled points, only marking firmly where shown.



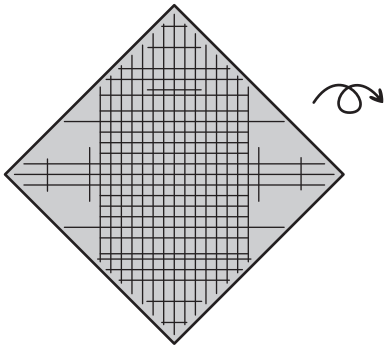
9. Fold and unfold the raw corners to the creases you just made, only marking firmly where shown.



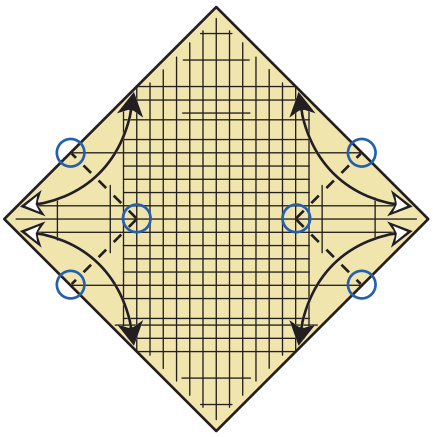
10. Fold and unfold six horizontal lines by bringing the raw corners to the circled points, marking firmly only where shown.



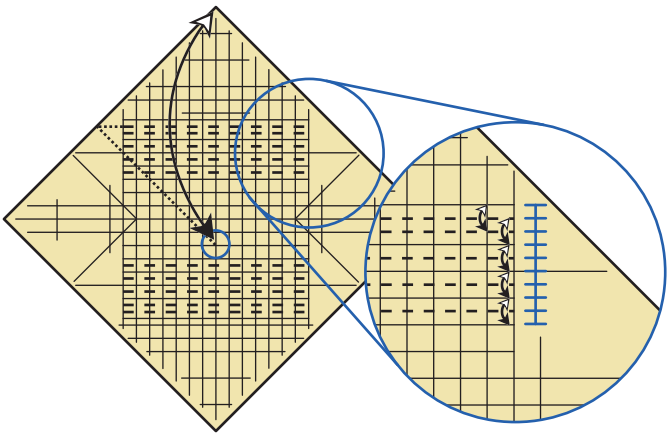
11. Fold and unfold four horizontal lines where shown.



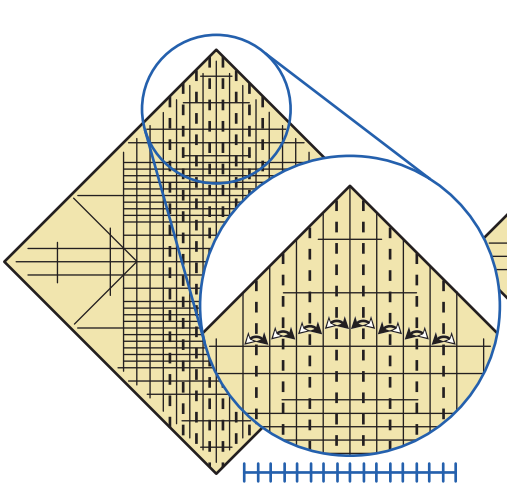
12. Turn the paper over.



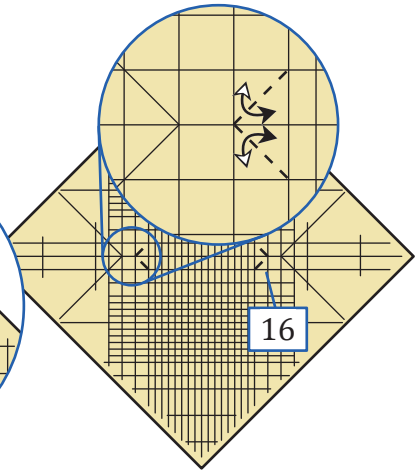
13. Fold and unfold four diagonal lines.



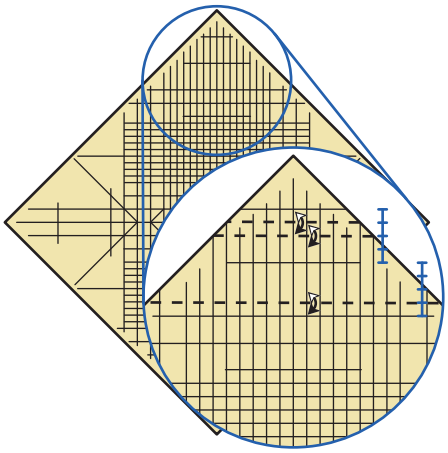
14. Fold and unfold ten horizontal lines where shown. (You can use the raw corner to help you – the topmost fold is shown as an example here.)



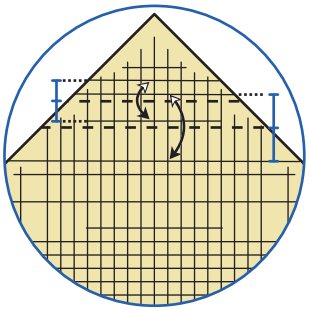
15. Fold and unfold eight vertical lines where shown.



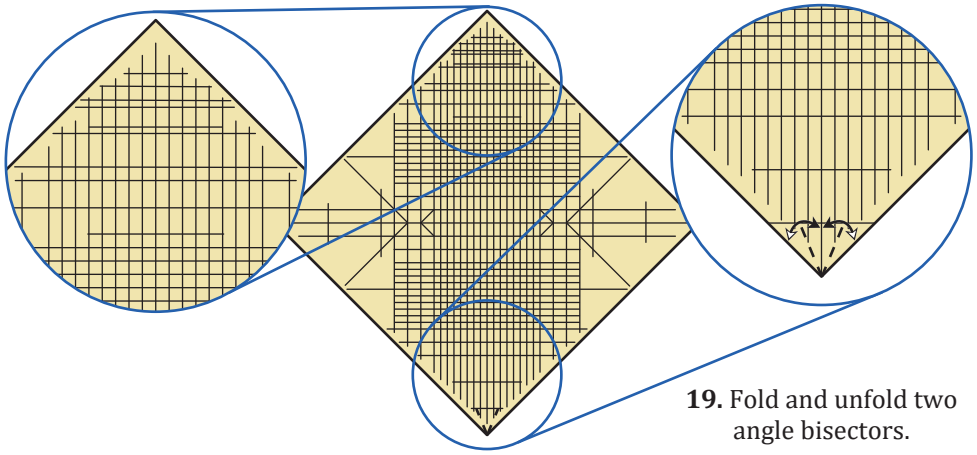
16. Fold and unfold two angle bisectors. Repeat on the right.



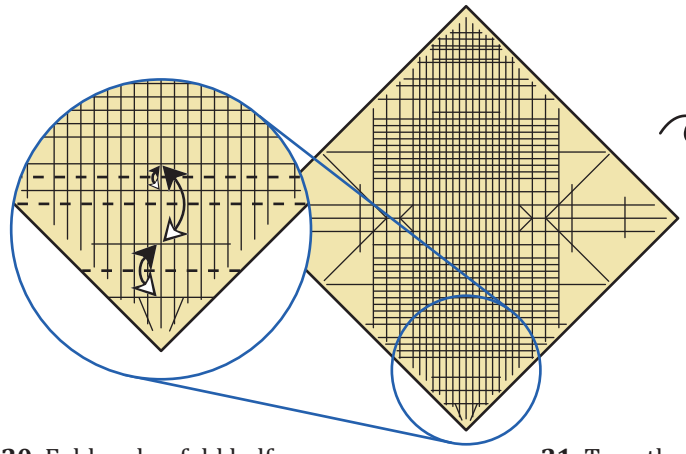
17. Fold and unfold three horizontal lines where shown.



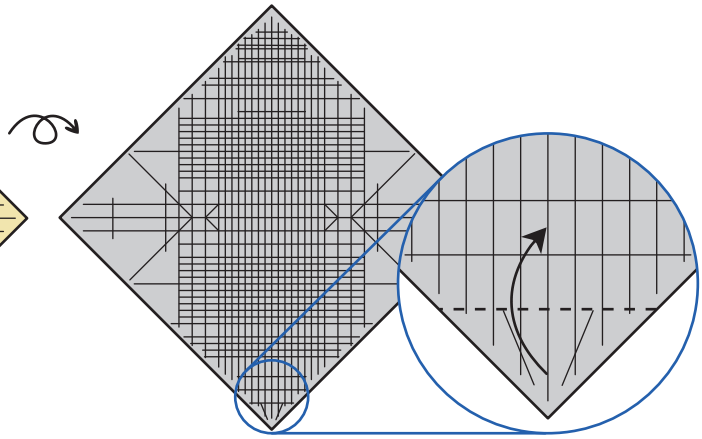
18. Fold and unfold two horizontal lines halfway between the indicated creases.



19. Fold and unfold two angle bisectors.

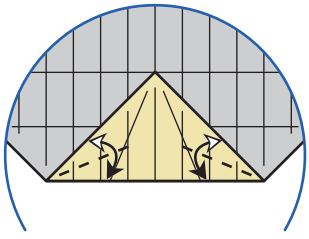


20. Fold and unfold halfway between the indicated pairs of creases.

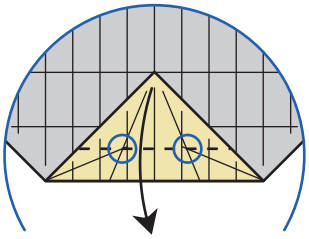


21. Turn the paper over.

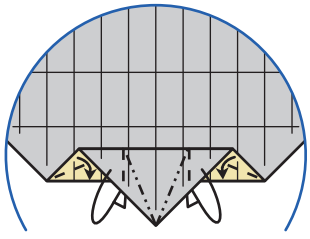
22. Fold the raw corner up using an existing crease.



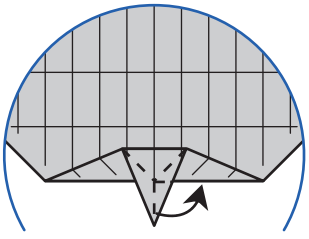
23. Fold and unfold two angle bisectors.



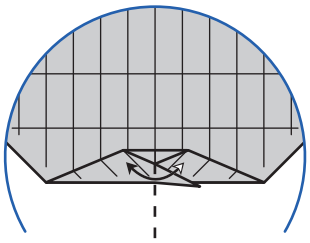
24. Fold the raw corner down using a fold-line which passes through the intersection of creases from steps 19 and 23.



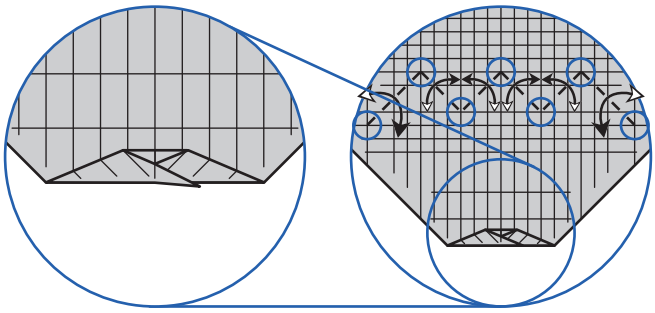
25. Swivel-fold on each side.



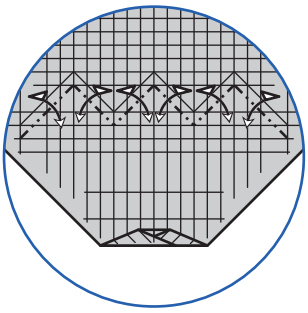
26. Rabbit-ear the raw corner to the right.



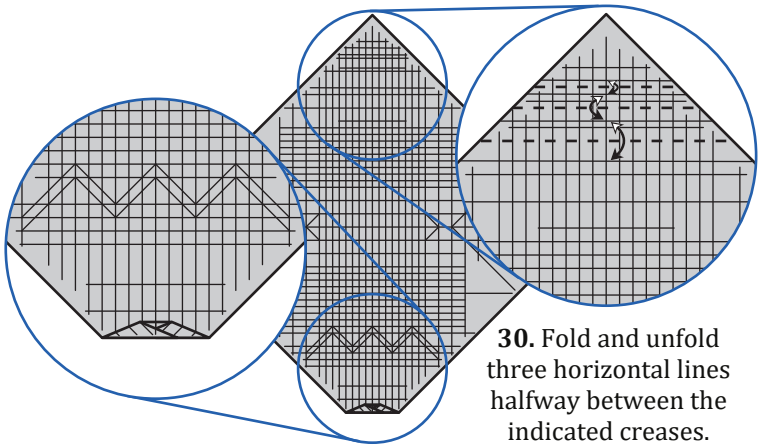
27. Fold and unfold. From now on, the raw corner will sometimes need to be folded left or right so that it is out of the way, even when this is not explicitly stated.



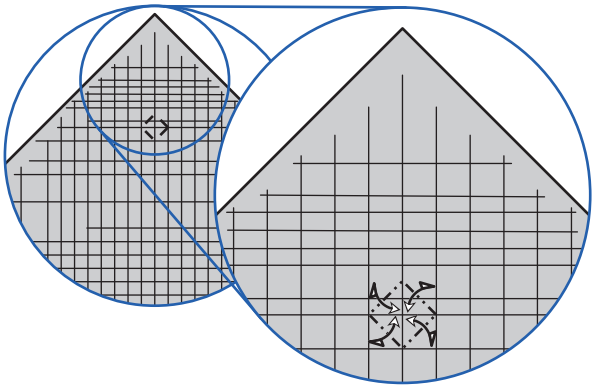
28. Fold and unfold six fold-lines which connect the circled points.



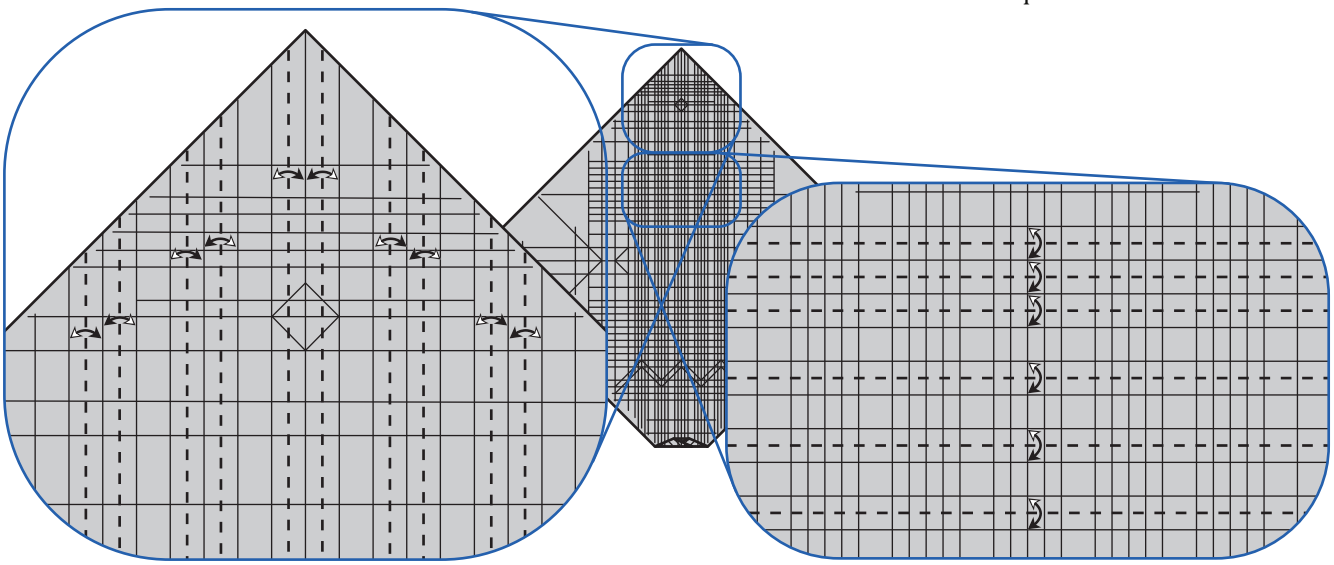
29. Pinch and unfold six fold-lines as **mountain folds**.



30. Fold and unfold three horizontal lines halfway between the indicated creases.

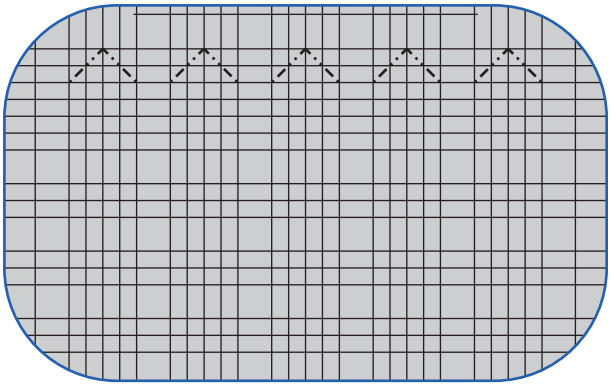


31. Pinch and unfold a small square of **mountain folds**.

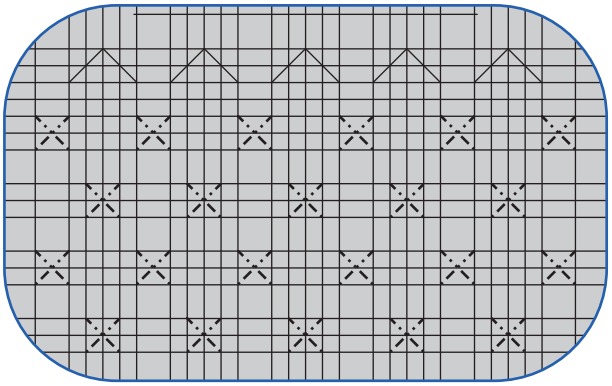


32. Fold and unfold ten vertical lines down the whole paper. You may find it easiest to make each fold-line by pleating the surrounding pair of creases together.

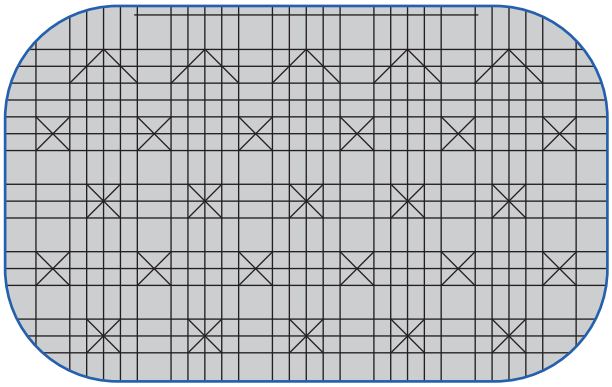
33. Fold and unfold six horizontal lines where shown (to the same width as the surrounding horizontal creases). You may find it easiest to pleat these.



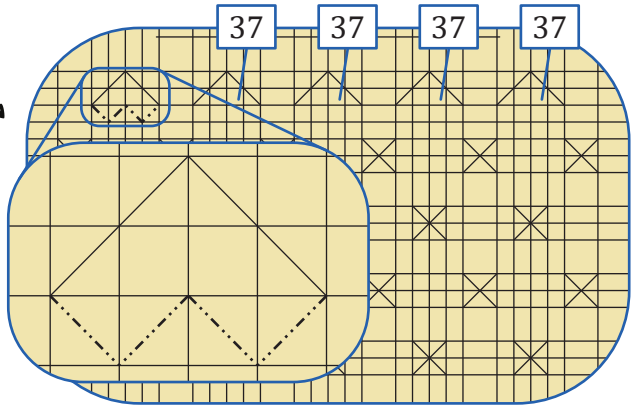
34. To prevent clutter, steps 34 to 40 won't have arrows. Pinch and unfold five pairs of **mountain folds**.



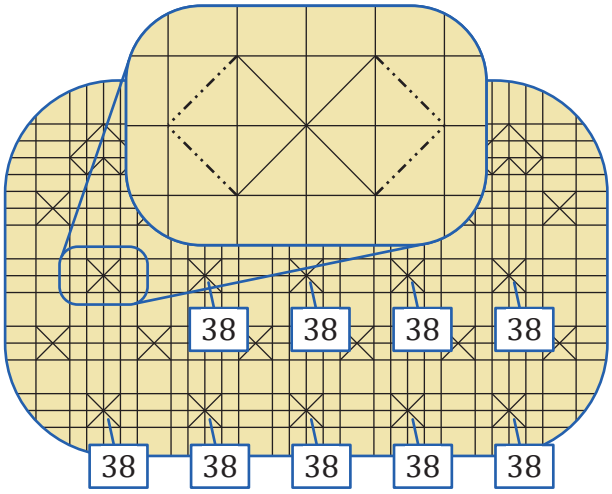
35. Pinch and unfold several pairs of **mountain folds** where shown.



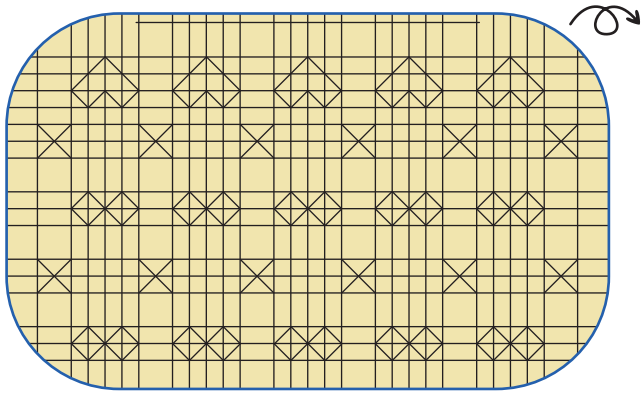
36. Turn the paper over.



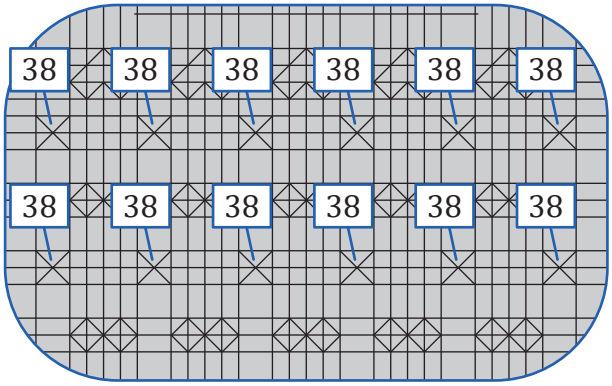
37. Pinch and unfold four **mountain fold-lines**. Repeat four times.



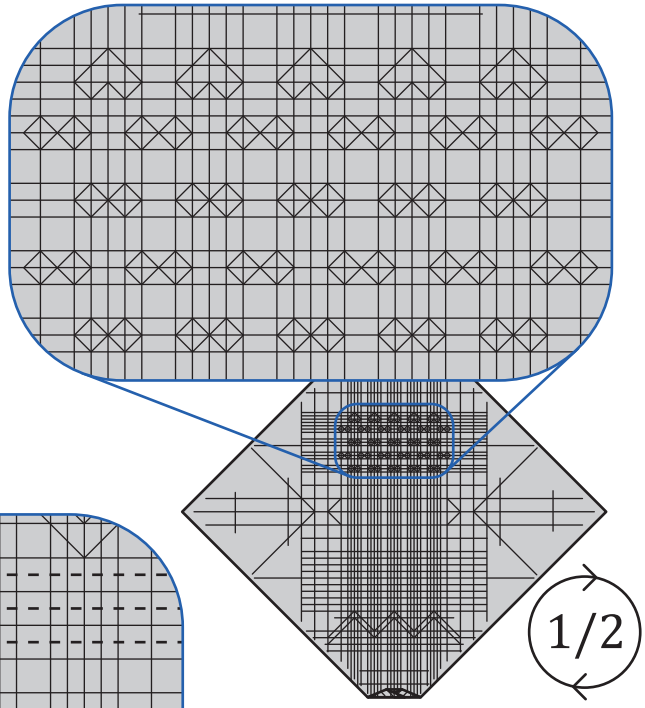
38. Pinch and unfold four **mountain fold-lines**. Repeat nine times.



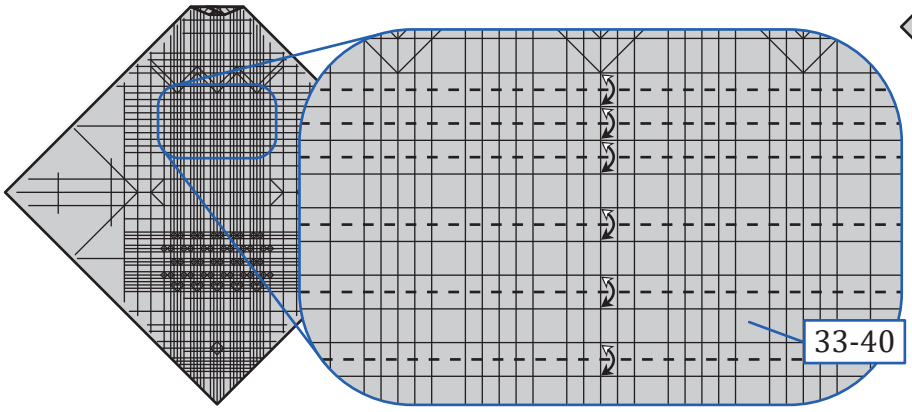
39. Turn the paper over.



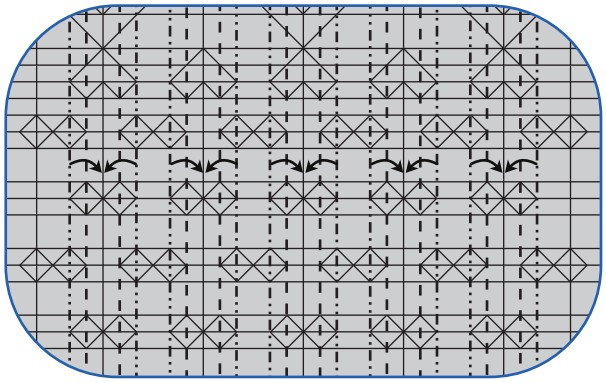
40. Repeat step 38 twelve times.



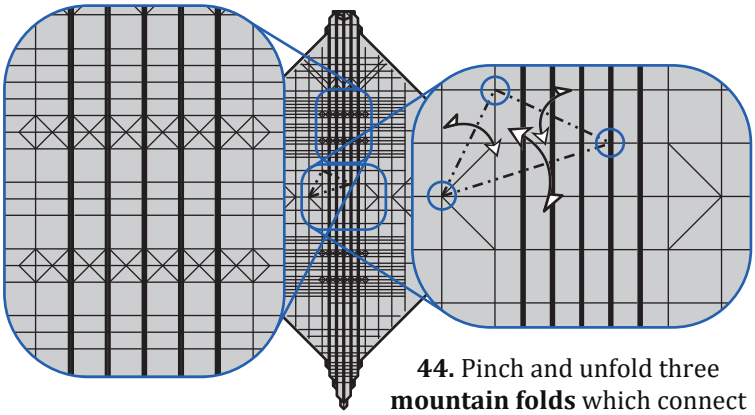
41. Make sure you have all the creases shown here. Rotate the paper ½ a turn.



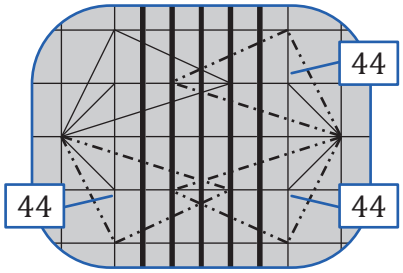
42. Repeat steps 33 to 40.



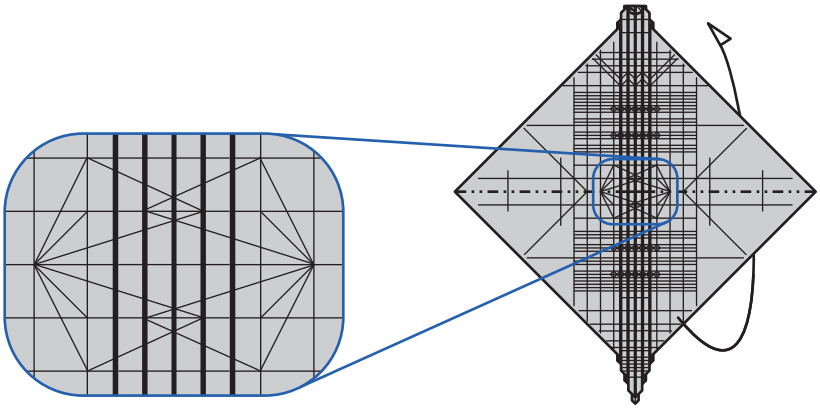
43. Pleat using existing creases.



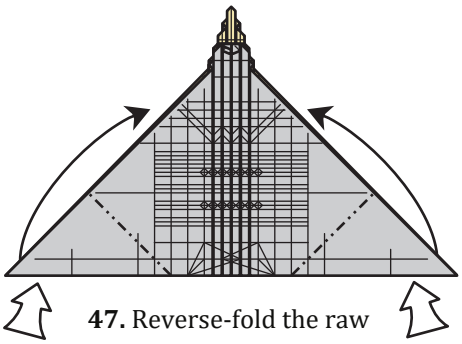
44. Pinch and unfold three **mountain folds** which connect the circled points.



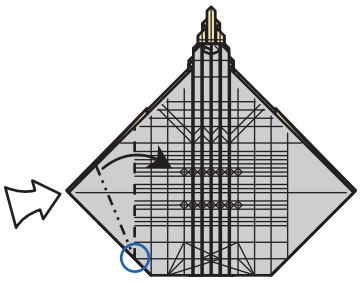
45. Repeat step 44 three more times.



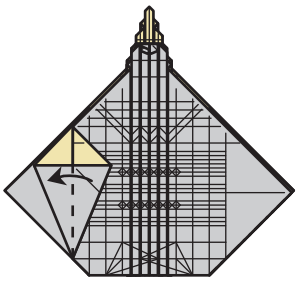
46. Mountain-fold the bottom half of the paper behind the top half.



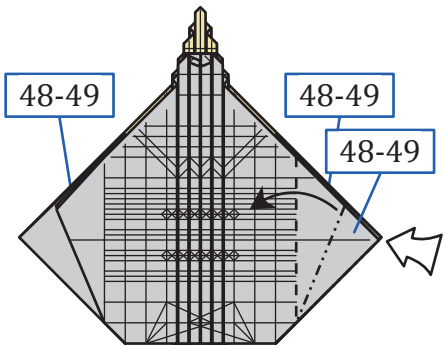
47. Reverse-fold the raw corners up.



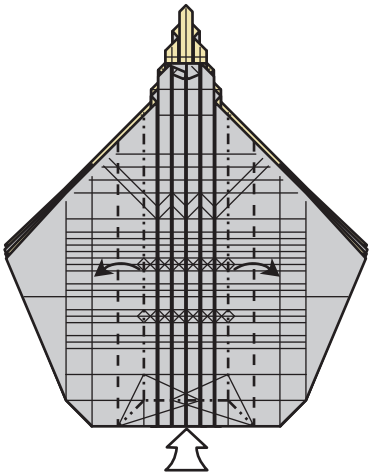
48. Squash-fold the near left corner.



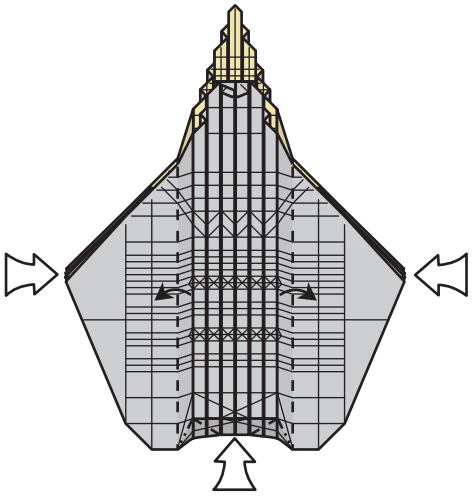
49. Fold the flap to the left.



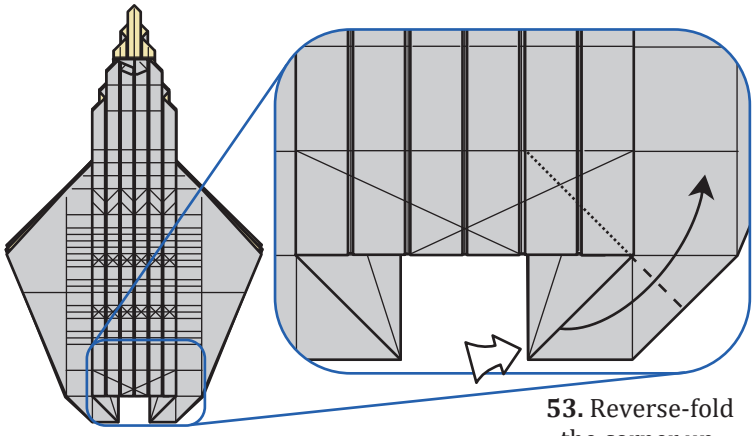
50. Repeat steps 48 and 49 three more times.



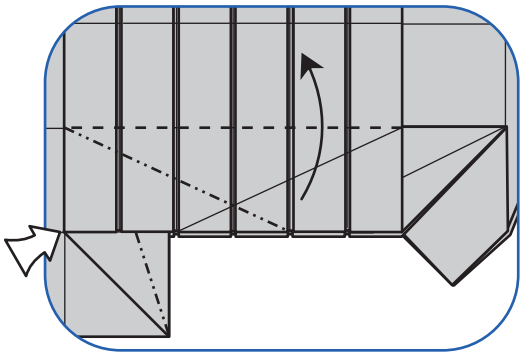
51. Begin to collapse the middle of the bottom edge upwards. The paper will not lie flat until after step 52.



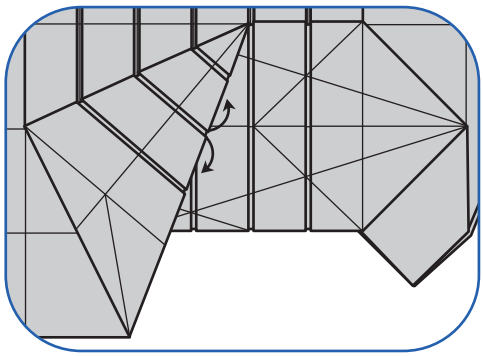
52. Continue to push the bottom edge up. Push the sides in using two pleats on both the front and the back, then flatten the paper.



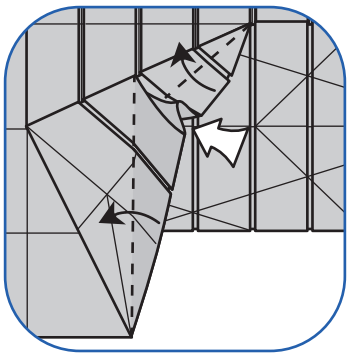
53. Reverse-fold the corner up.



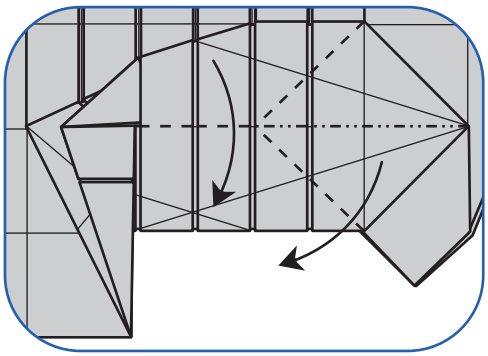
54. Lift the folded edge and spread-sink the corner using mountain folds that were formed in step 44.



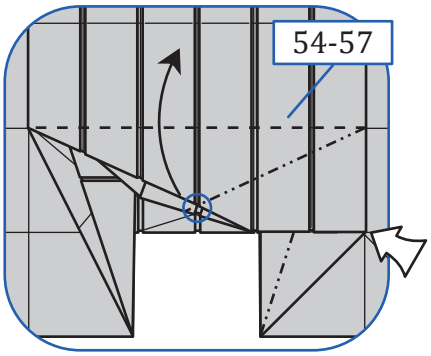
55. Very carefully stretch the central pleat as far as it will go. The paper won't lie flat.



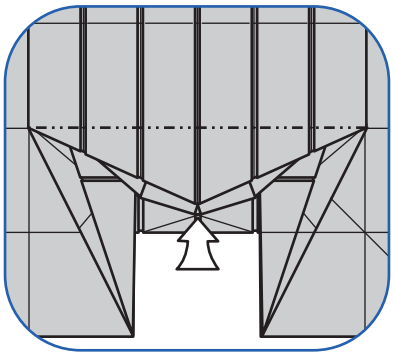
56. Flatten the paper up and to the left (the paper will naturally form a very small new pleat on each side in the region of stretched paper).



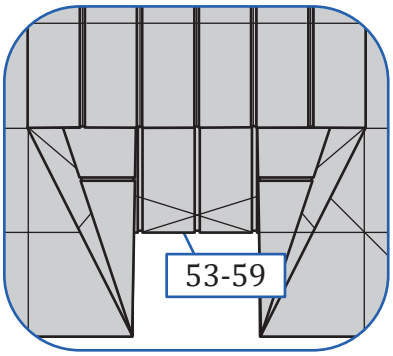
57. Fold the edge down, undoing step 53.



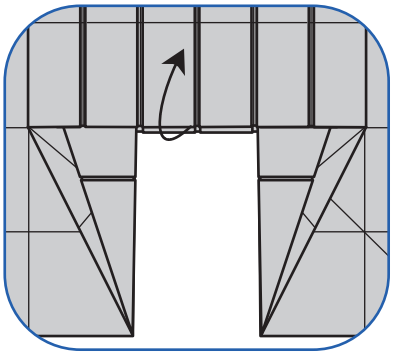
58. Repeat steps 54 to 57 on the right. The circled point won't lie flat until after you repeat step 56.



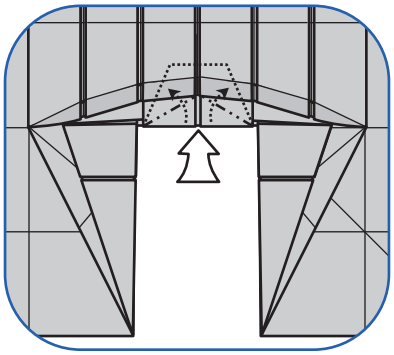
59. Closed-sink the flap inside. (Don't worry about doing this step neatly.)



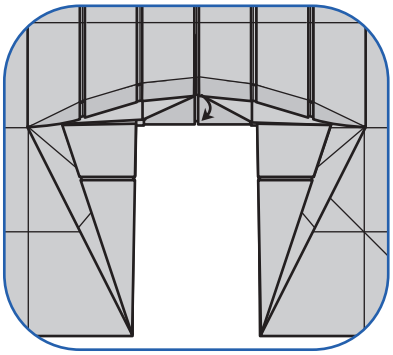
60. Repeat steps 53 to 59 behind.



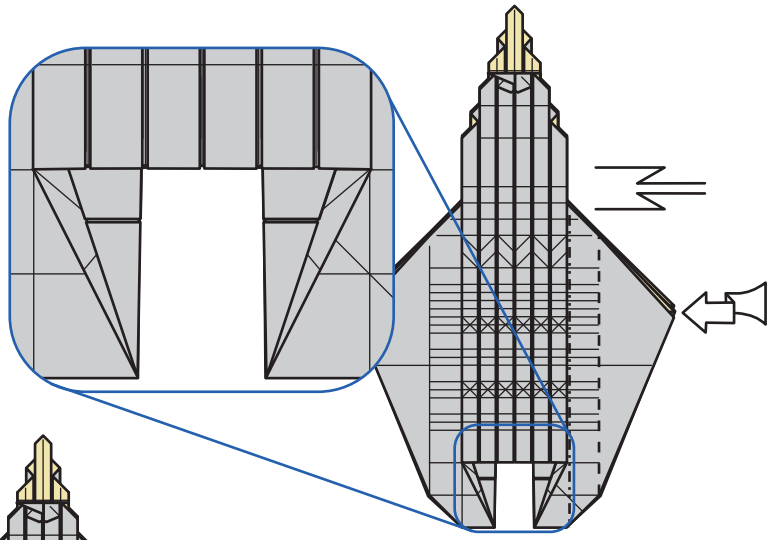
61. Lift the near edge.



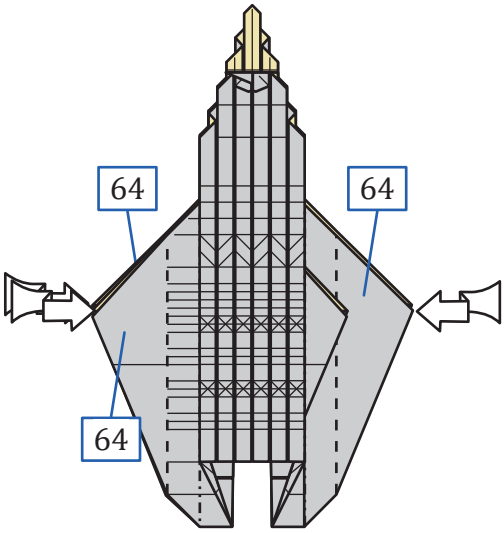
62. Spread the central pleat and push the edge up inside the paper as far as it will go.



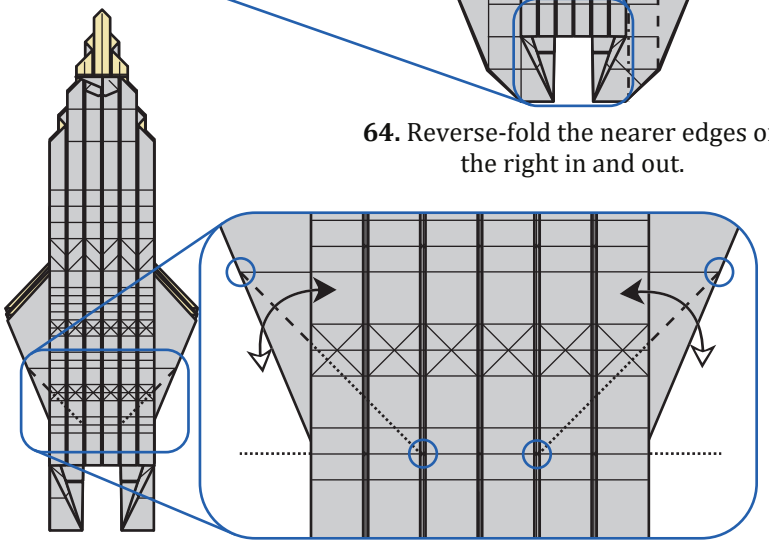
63. Flatten the paper again.



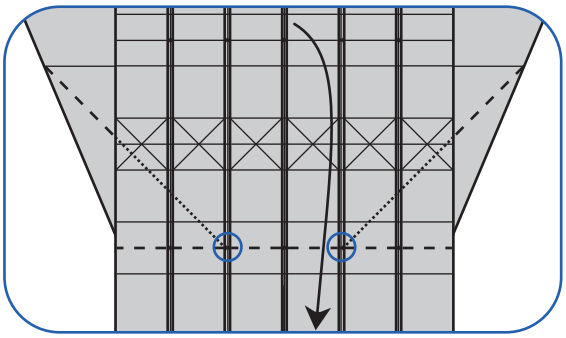
64. Reverse-fold the nearer edges on the right in and out.



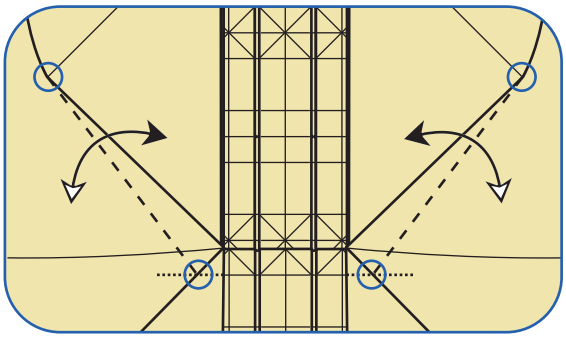
65. Repeat step 64 three times: on the left and twice behind.



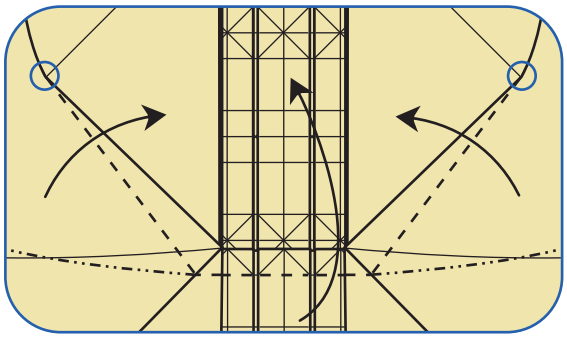
66. Fold and unfold two fold-lines: these connect the upper circled points to the hidden vertical edge at the indicated horizontal line. Fold these in one layer only. You may find it easiest to make these as mountain folds by opening up the paper – see step 67.



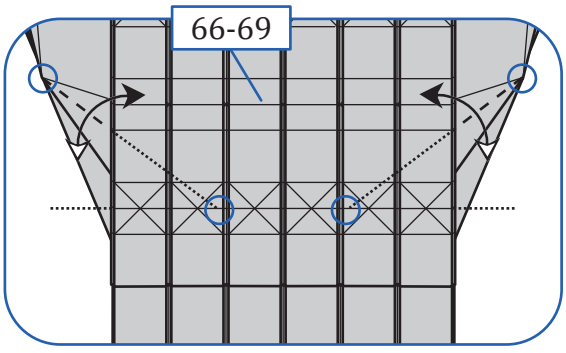
67. Fold the near section of paper down using the lines from step 66, and squash the central section flat where those fold-lines meet at the circled points. The outer regions of paper won't lie flat until after step 69.



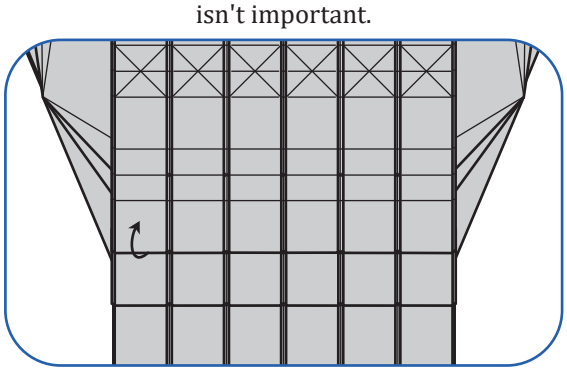
68. Fold and unfold two fold-lines which connect the upper circled points to the intersections between the indicated horizontal crease and the folded edges.



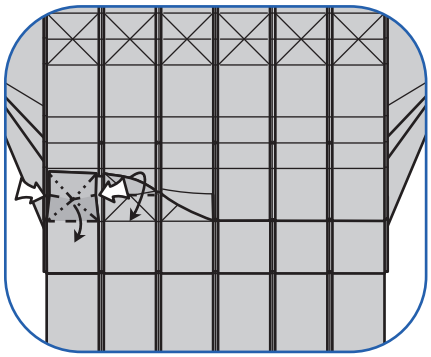
69. Fold the near layers back up using creases you just made and existing horizontal creases, then flatten the paper (which will create the new mountain fold-lines). The exact location of fold-lines above the circled points isn't important.



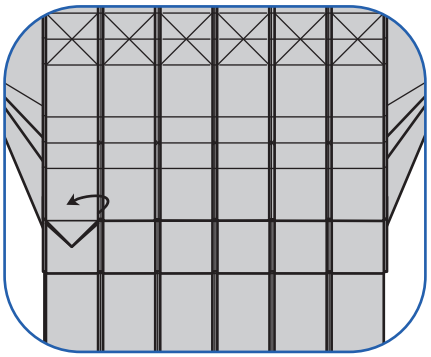
70. Repeat steps 66 to 69 on the next pleat.



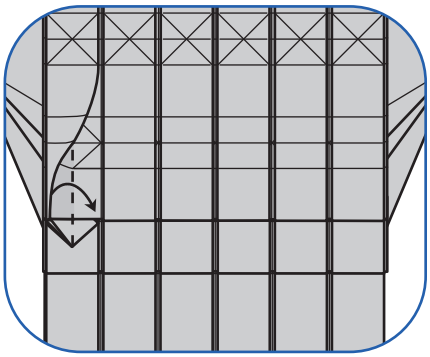
71. Lift the left section of the upper pleat.



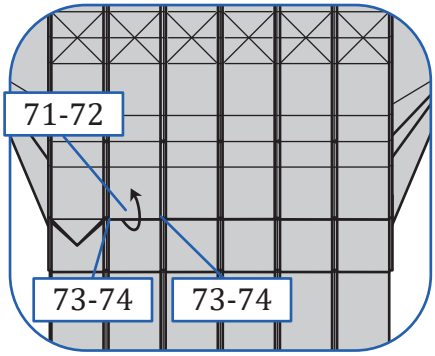
72. Carefully pull the corner down, squeeze the sides in using existing creases, and flatten the paper. The corner becomes a very small Waterbomb Base.



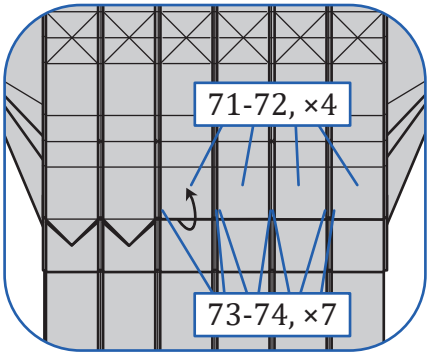
73. Lift the edge to the left and carefully spread the pleat. (You may have done this already in step 72, which is fine).



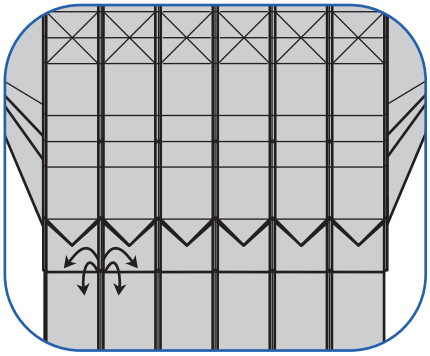
74. Fold the edge back down.



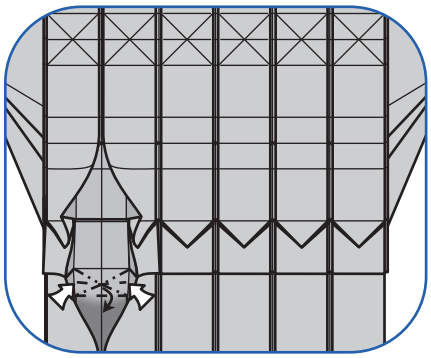
75. Repeat steps 71 and 72 to make a new corner, and repeat steps 73 and 74 on both sides of the new corner.



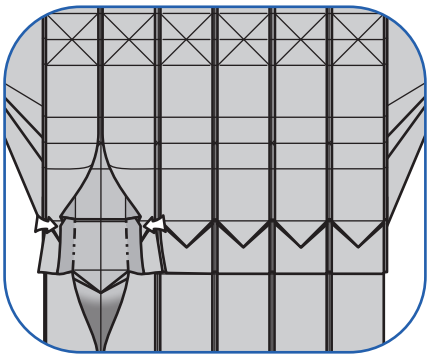
76. Continue along the row: pull four more corners out and spread the pleats between them.



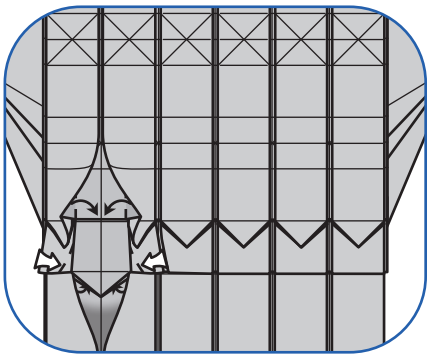
77. Carefully open the pleats on the left in the second row. Try to avoid opening any other pleats. Note that steps 78 to 80 are very fiddly, and you may find it easier to work on all of these steps simultaneously.



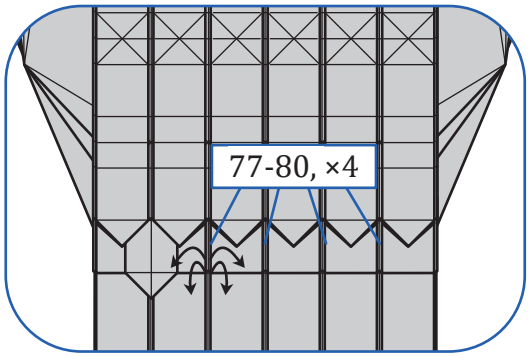
78. Use existing creases to make a corner, like in a Waterbomb Base, and pull it downwards.



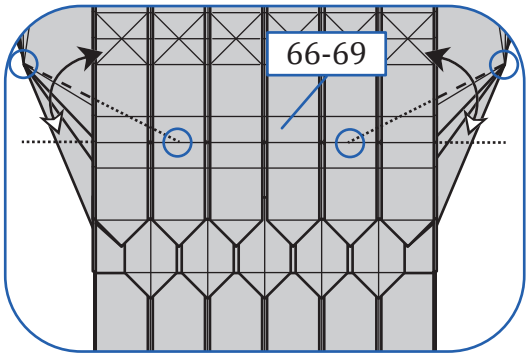
79. Closed-sink the corners at the top of each edge in order to turn two valleys into mountains.



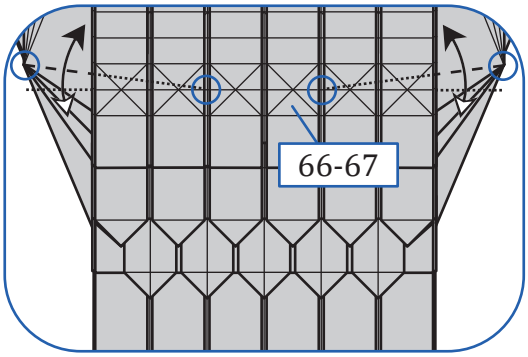
80. Flatten the paper.



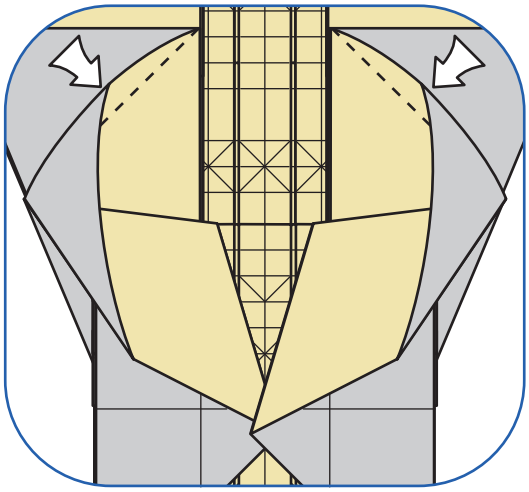
81. Repeat steps 77 to 80 four times.



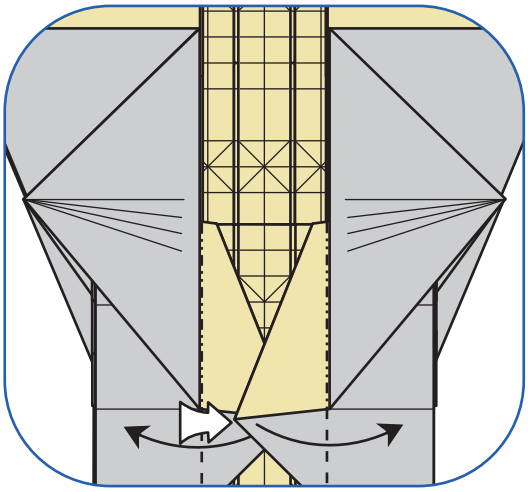
82. Repeat steps 66 to 69 on the next pleat.



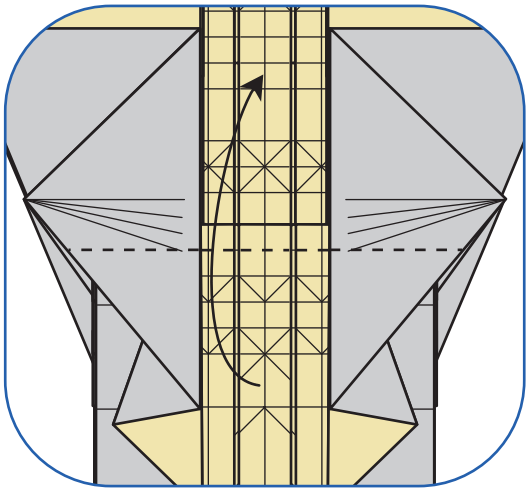
83. Repeat steps 66 and 67 on the next pleat.



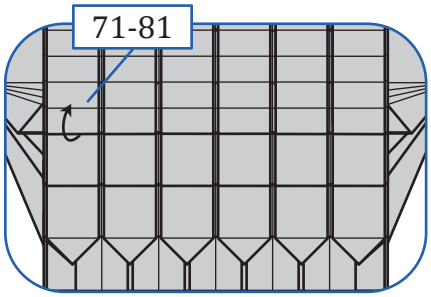
84. Squash-fold the raw edges so that they become vertical.



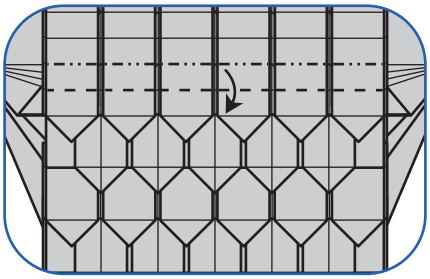
85. Reverse-fold the corners outwards. You will need to lift the flap up to achieve this.



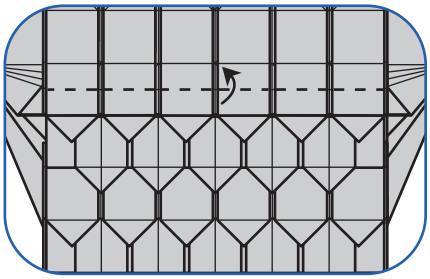
86. Fold the flap up.



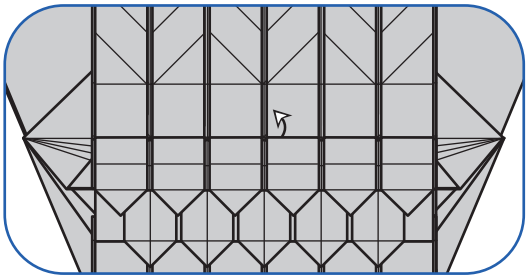
87. Repeat steps 71 to 81.



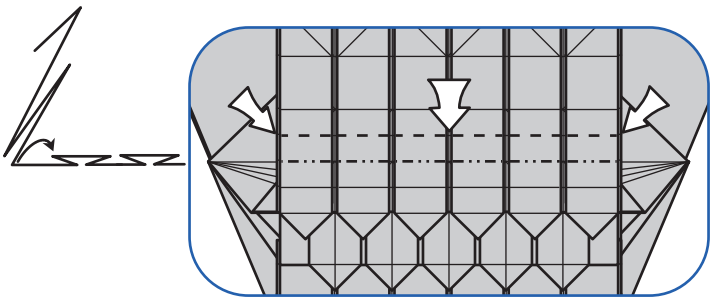
88. Pleat using existing creases.



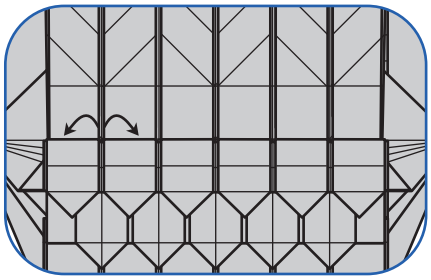
89. Fold the edge up.



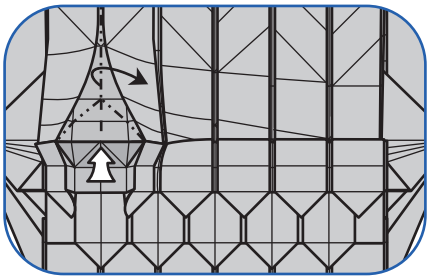
90. Make sure the creases are firmly in place in the far layers of the tall flap. Unfold the flap, undoing steps 88 and 89.



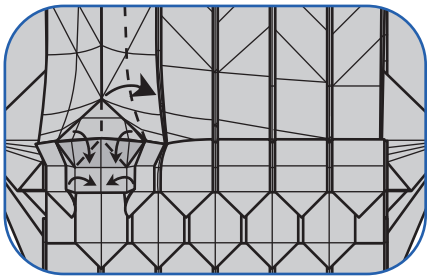
91. Mixed-sink the flap in and out: the paper goes down directly behind the visible layers at the front, locking the paper at the sides.



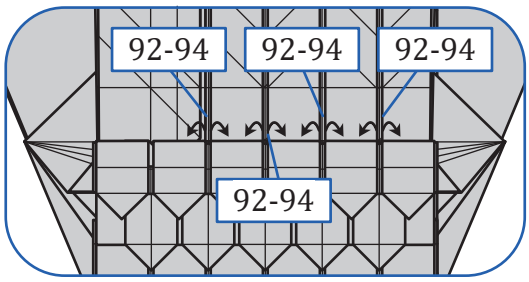
92. Carefully open the leftmost pleat.



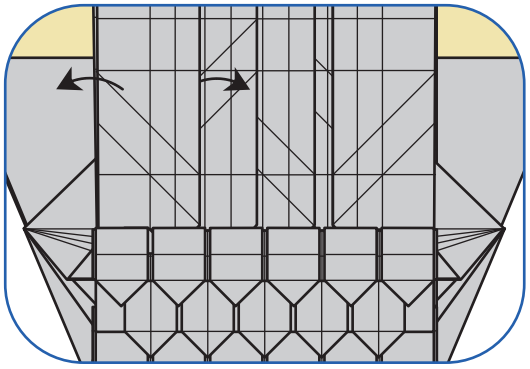
93. Pinch the existing mountain folds shown and pull the vertical mountain to the front.



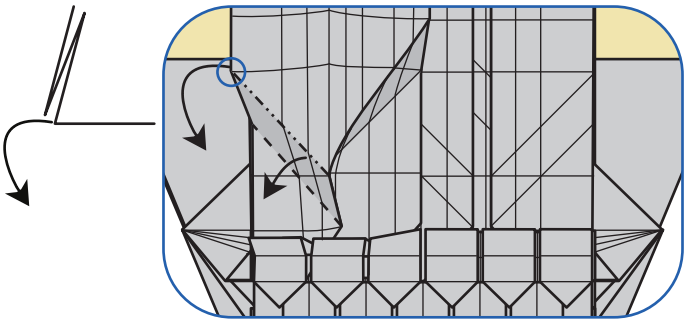
94. Fold the ridge towards the centre of the paper and flatten the paper using existing creases.



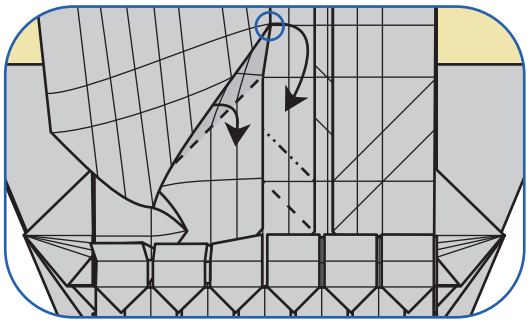
95. Repeat steps 92 to 94 four times: fold the central pleat last, folding the ridge to the right. From now on you will sometimes need to fold the horizontal pleat up or down to achieve some future steps, even if not explicitly stated.



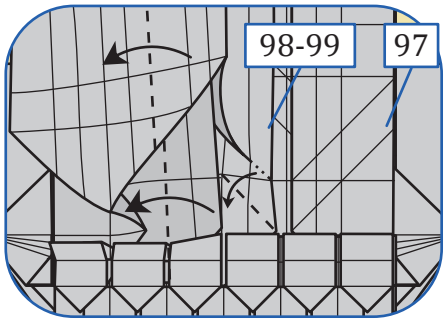
96. Spread the nearest pleat. The paper won't lie flat until after step 99.



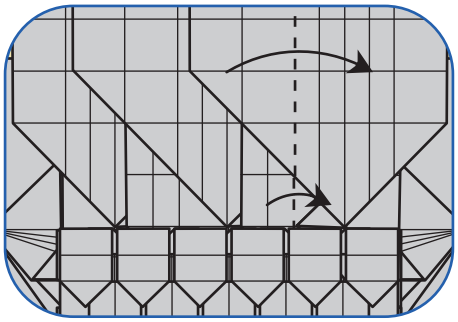
97. Wrap the circled corner around the left edge and begin to collapse the mountain fold shown to the left.



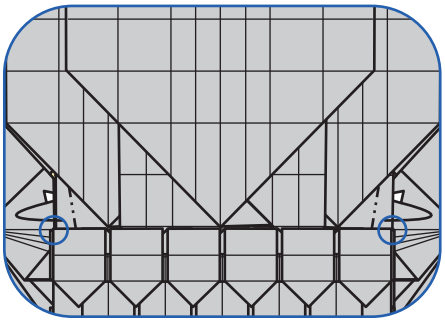
98. Wrap the circled point around the right edge and begin to collapse the next pair of diagonal pleats.



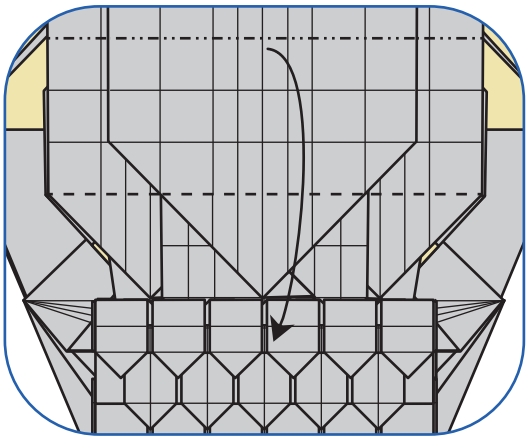
99. Fold the ridge to the left. Continue alternating between steps 98 and 99 all the way across the flap until the paper is flat, then repeat step 97 on the right.



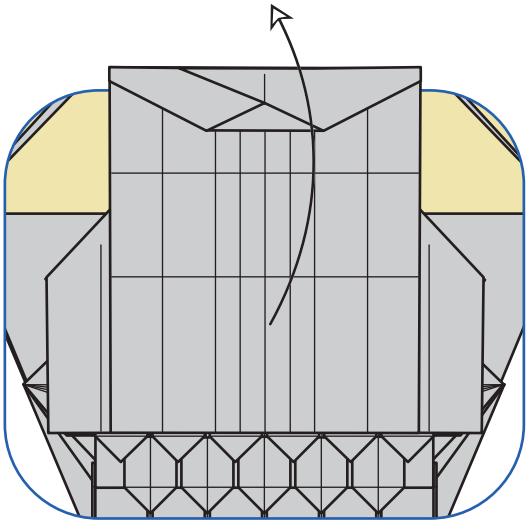
100. Fold one flap back to the right. (This requires a very small reverse-fold at the bottom.)



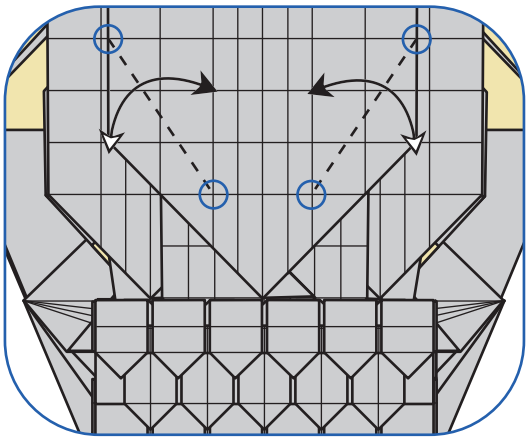
101. Carefully stretch the paper apart at the circled corners so that you can mountain fold the edges behind.



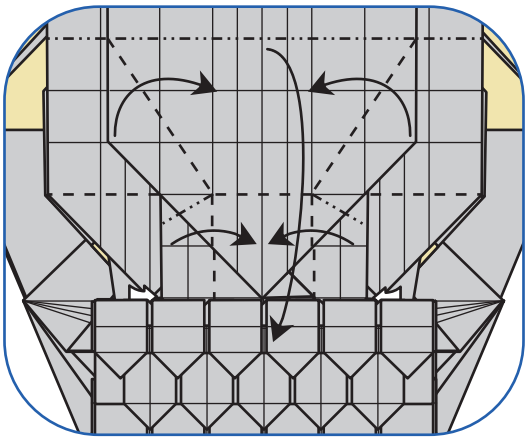
102. Pleat the paper down and up using existing creases.



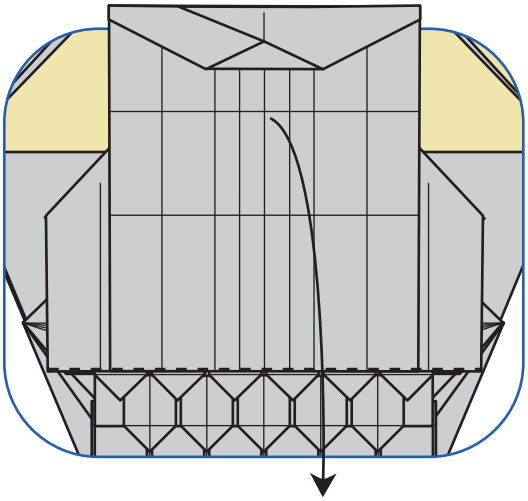
103. Unfold step 102.



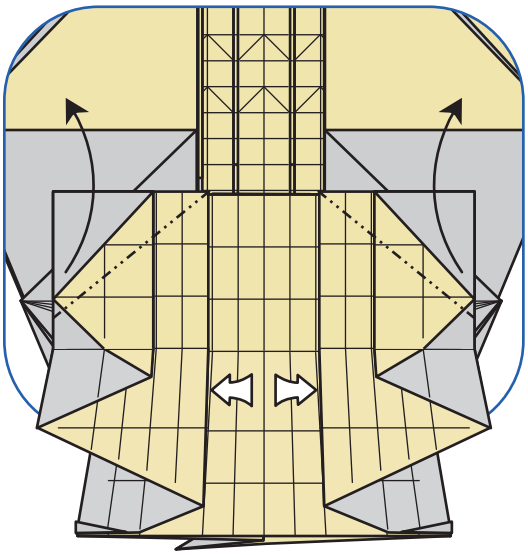
104. Fold and unfold two new valley fold-lines in the nearest two layers which connects the circled points.



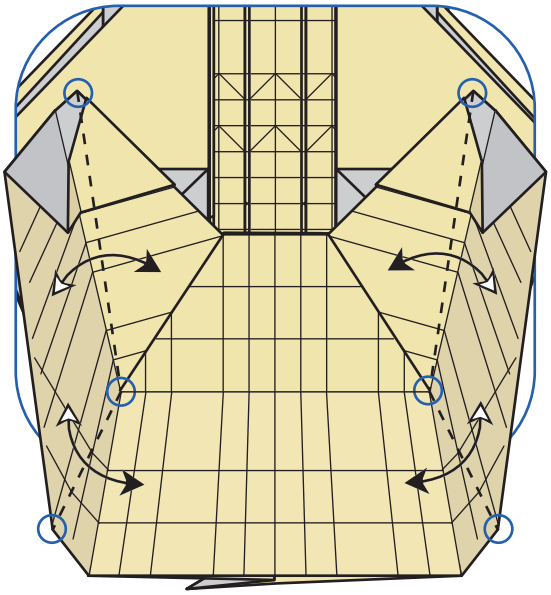
105. Refold step 102, but use the creases from step 104 to bring two vertical pleats into the centre.



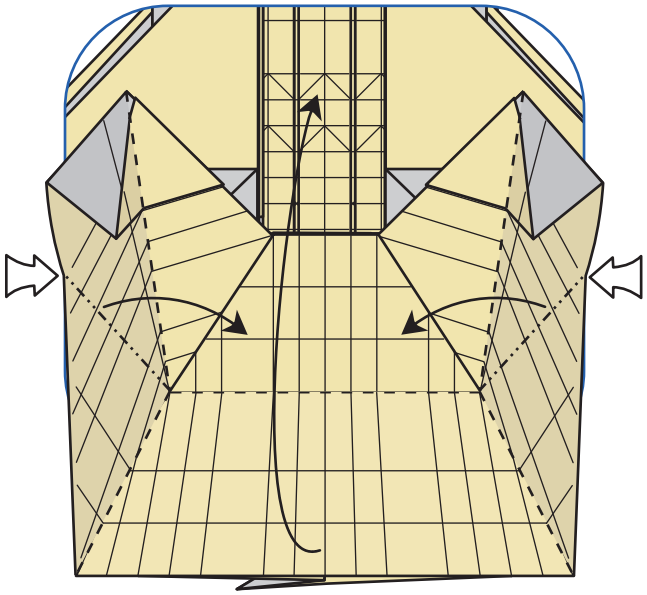
106. Fold the near layers towards you so that they stick out perpendicular from the paper. The paper won't lie flat until after step 109.



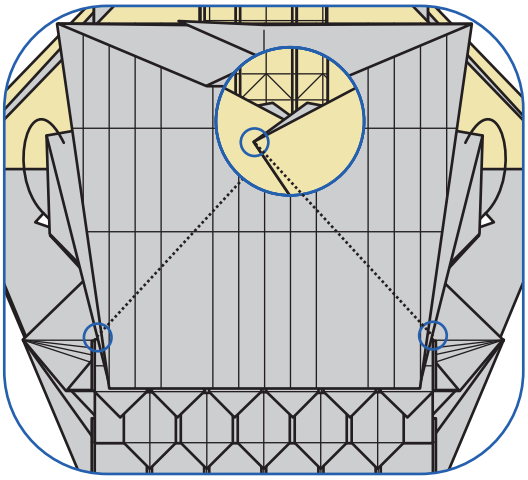
107. Pull the layers at the sides up as far as they will go – this will create a new mountain crease on each side.



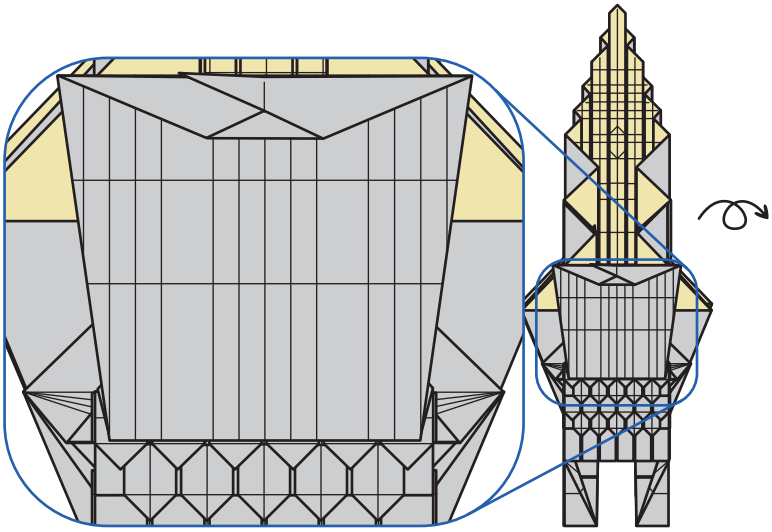
108. Fold and unfold four new valley fold-lines between the circled points.



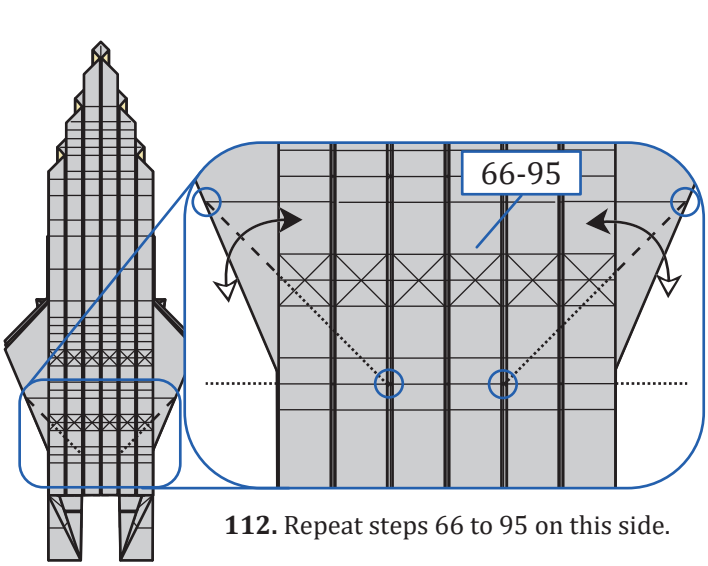
109. Collapse the paper using the creases you just made.



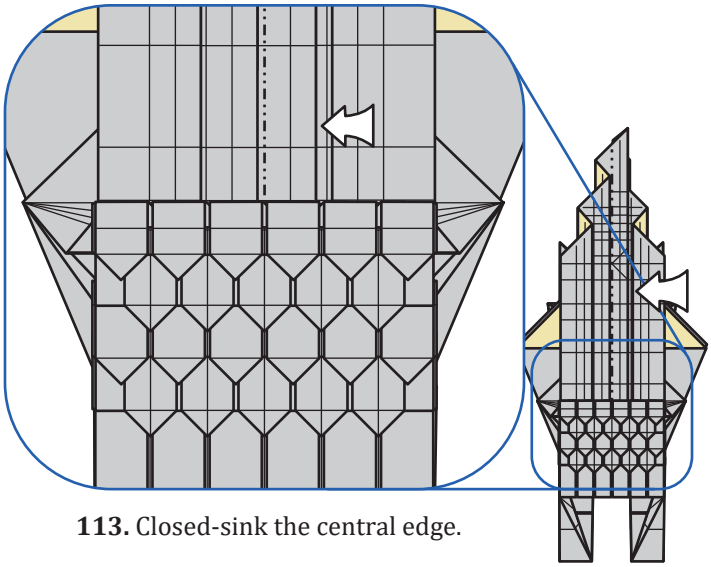
110. Mountain-fold some paper behind on each side, using the references shown.



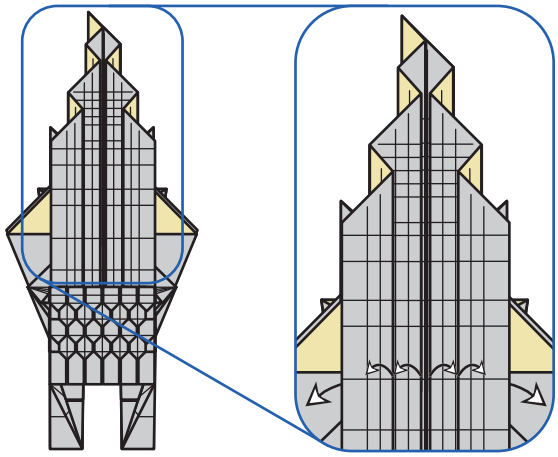
111. Turn the paper over.



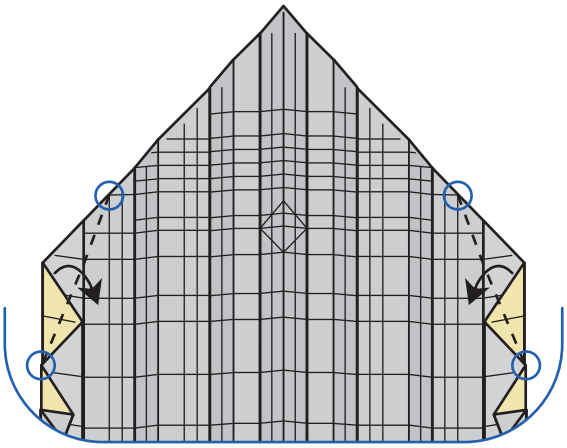
112. Repeat steps 66 to 95 on this side.



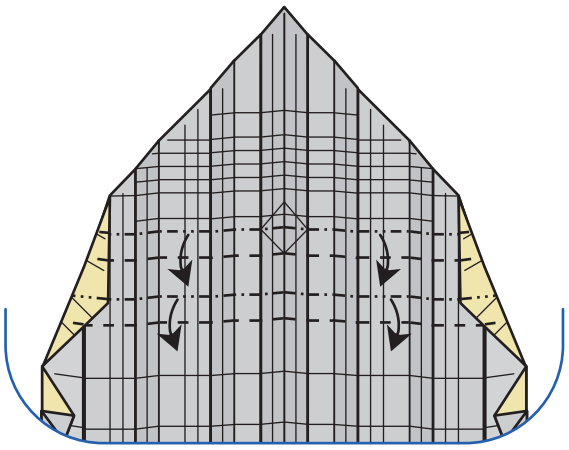
113. Closed-sink the central edge.



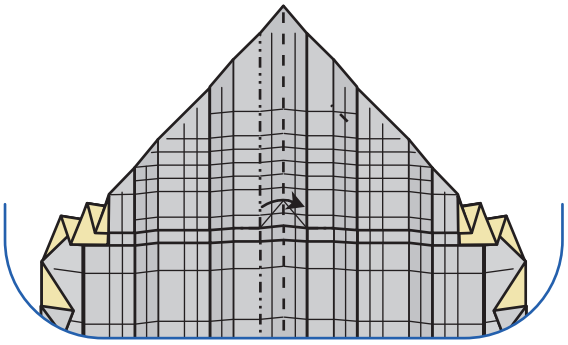
114. Open the top section: spread the near pleats, and fold the far edges at the sides to the front. The rest of the paper won't be shown until step 145. The paper is shown flat for clarity, but you won't actually be able to flatten the whole region at once. Do not try to!



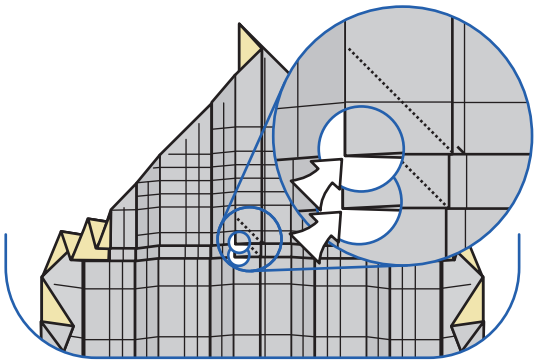
115. Fold two corners over using fold-lines which connect the circled points.



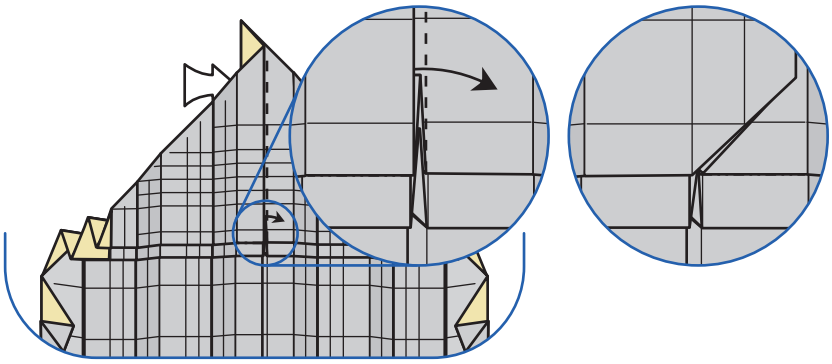
116. Pleat twice using existing creases.



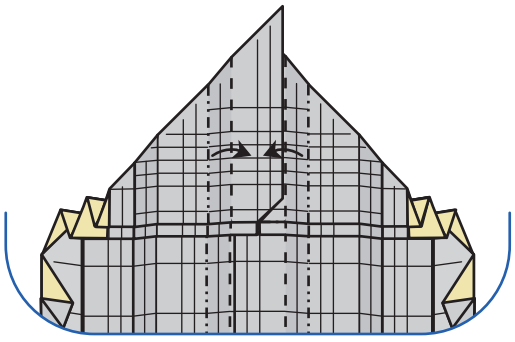
117. Pleat the left half over the right half.



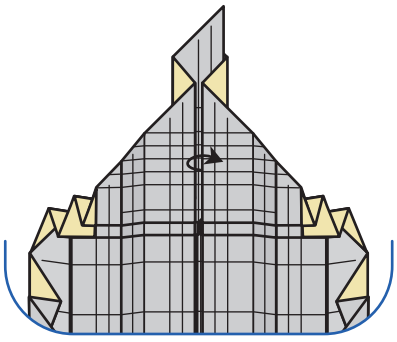
118. Reverse-fold two corners.



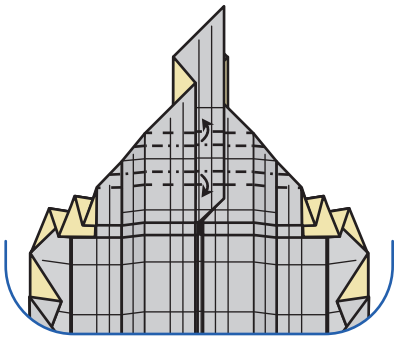
119. Unsink the edge to the right.



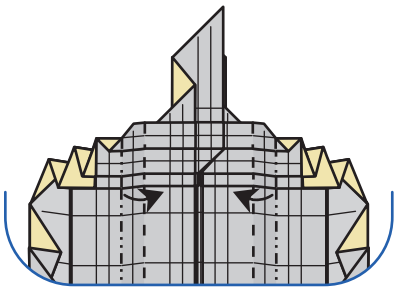
120. Pleat the sides in.



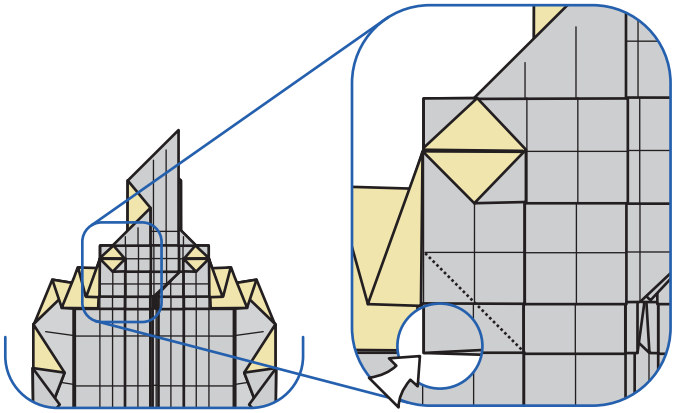
121. Bring the covered edge to the front.



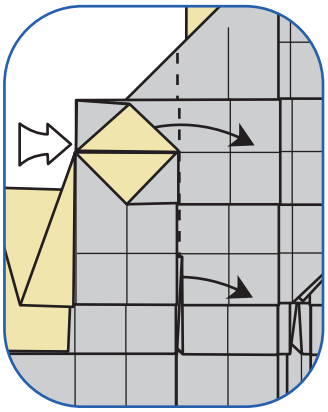
122. Pleat twice using existing creases.



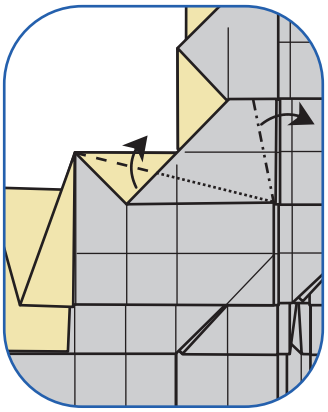
123. Pleat twice using existing creases.



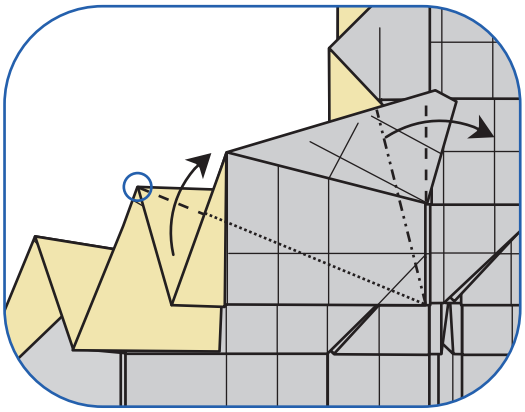
124. Reverse-fold a corner.



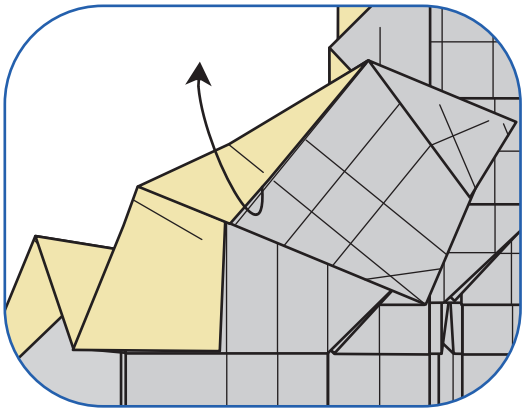
125. Unsink the edge: make sure you pull all layers of paper to the right.



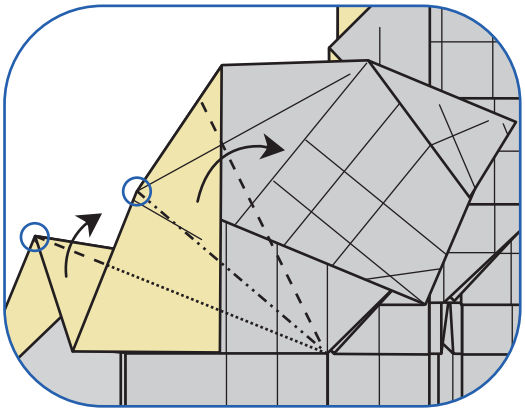
126. Swivel-fold the paper clockwise.



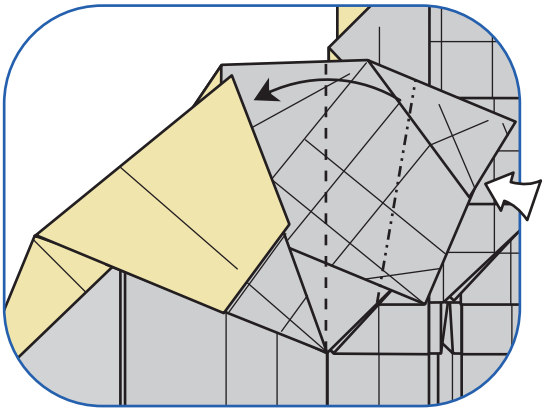
127. Swivel-fold the paper clockwise.



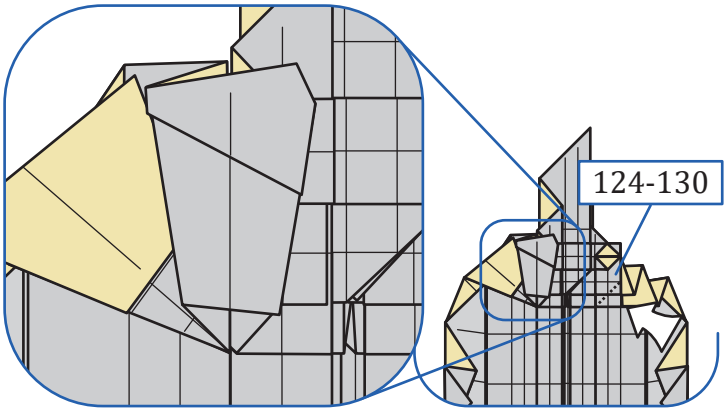
128. Pull out the raw edge.



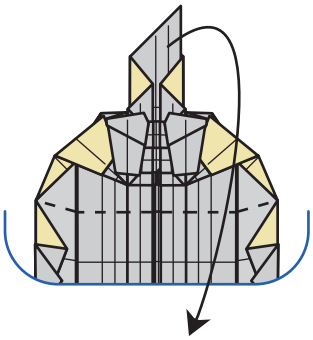
129. Swivel-fold the paper clockwise.



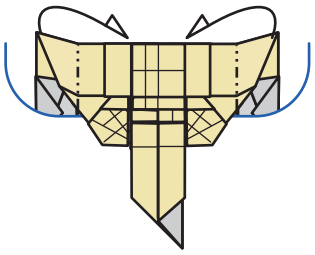
130. Spread-sink the layers evenly.



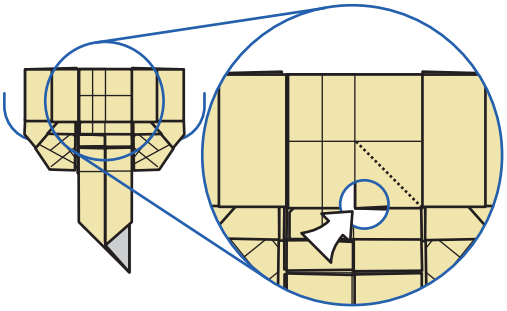
131. Repeat steps 124 to 130 on the right.



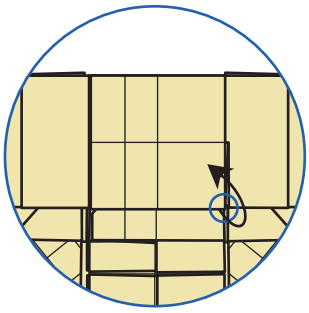
132. Fold the top down using an existing crease.



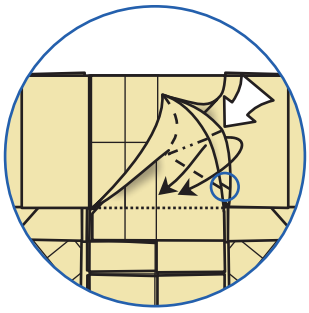
133. Mountain-fold the sides behind to flatten the paper.



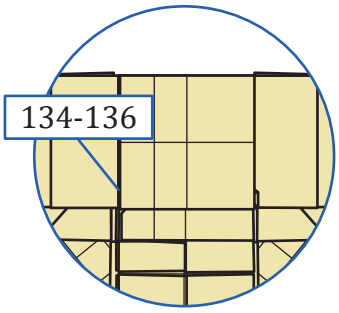
134. Reverse-fold a hidden corner.



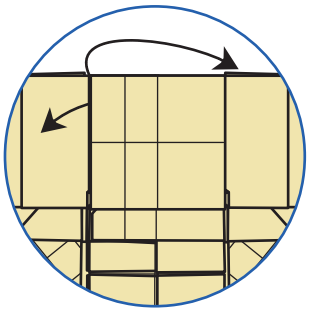
135. Carefully lift the edge and separate the pleats at the circled corner.



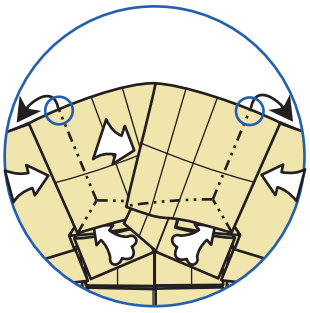
136. Flatten the paper and and bring both edges downwards. Note that the lower valley folds start slightly above the indicated horizontal line.



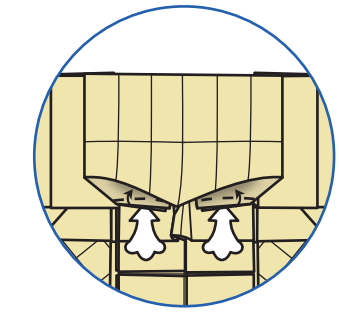
137. Repeat steps 134 to 136 on the left symmetrically – **not** in the nearest flap, but the layers under that.



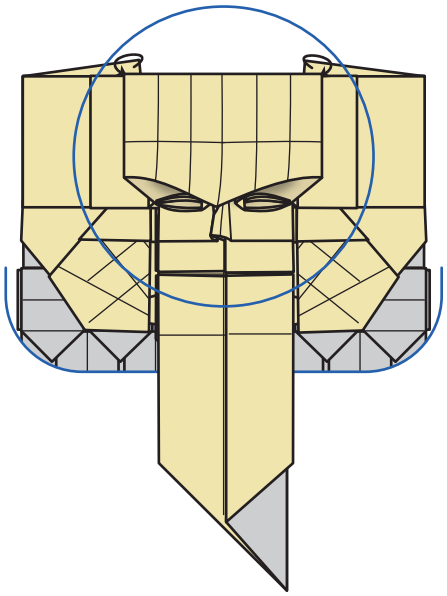
138. Spread the central pleat carefully. The paper will not lie flat from now on.



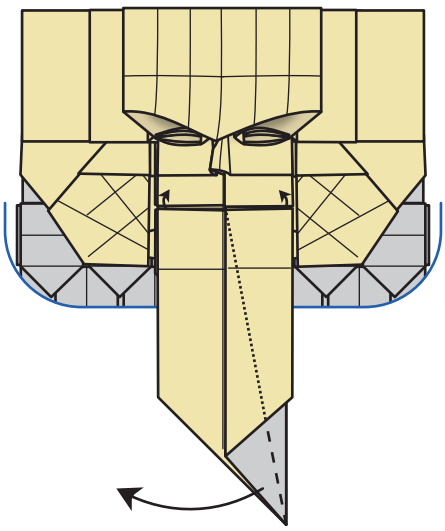
139. Put your fingers in the two pockets and slide them outwards to make new fold-lines where shown. The mountains at the circled points continue to the far layer (down and inside the model). Slide the paper at the sides underneath these lines, so that they move towards the centre.



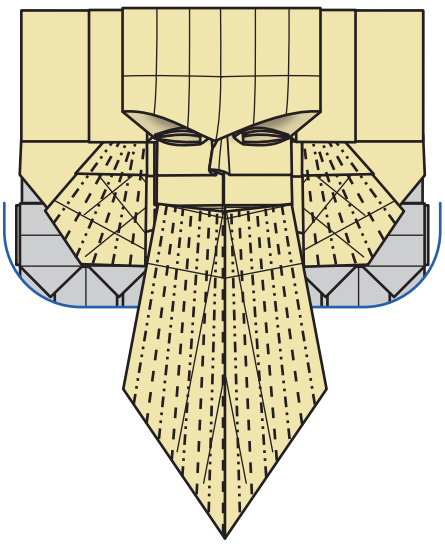
140. Open the layers to form eyes.



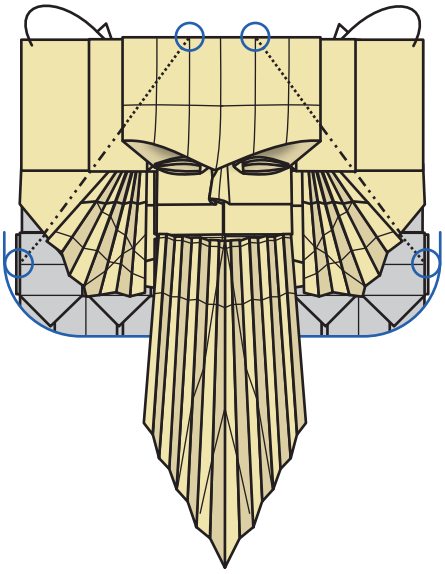
141. Tuck the corners at the top of the head underneath the edge on the back layer.



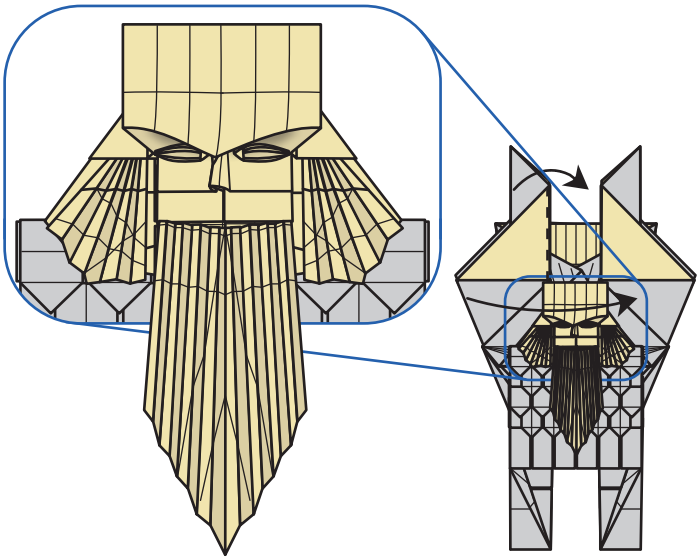
142. Spread the flap at the bottom so that the raw corner is in the centre.



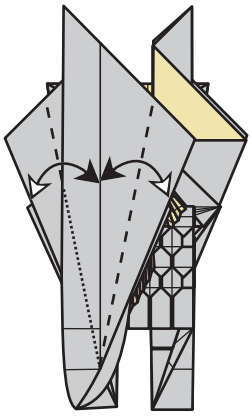
143. Make multiple narrow pleats across three flaps to make hair and a beard.



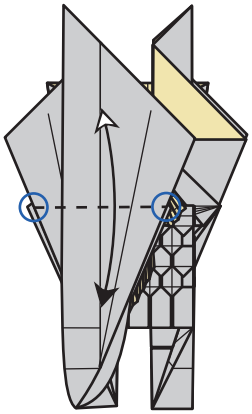
144. Mountain-fold the corners behind, tucking them under the vertical edges to lock them in place.



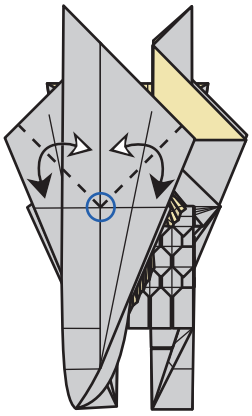
145. Fold everything that's in front of the central layer (but not that layer itself) to the right, but don't fold firmly. The paper won't lie flat at the bottom.



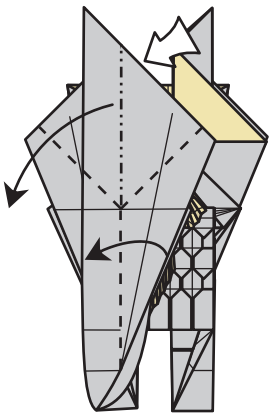
146. Fold and unfold two angle bisectors.



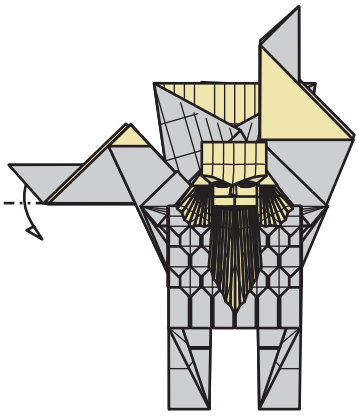
147. Fold a horizontal line and unfold.



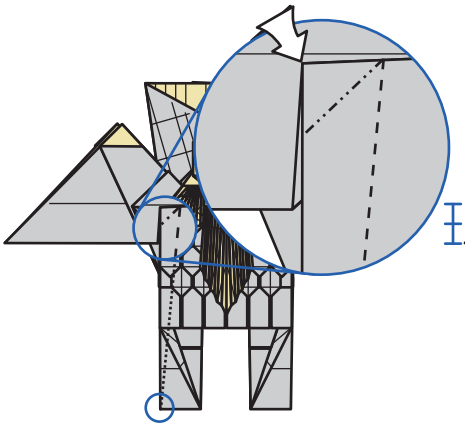
148. Fold and unfold two diagonal lines.



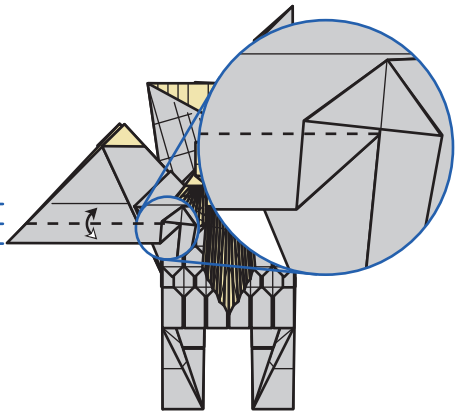
149. Use folds from steps 147 and 148 to close the flap and reverse-fold the corner down to the left.



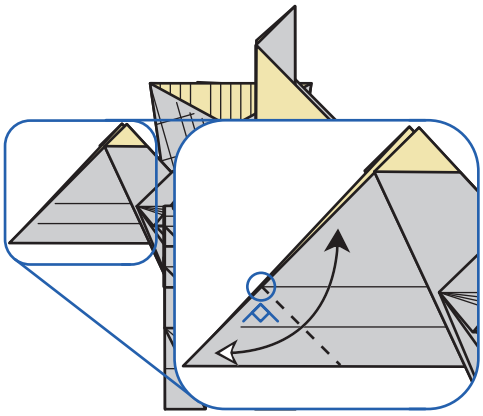
150. Mountain-fold the edge down.



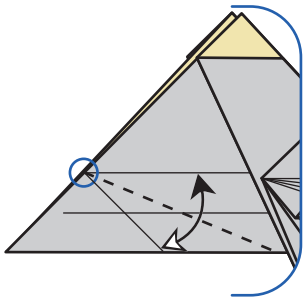
151. Squash-fold a hidden corner.



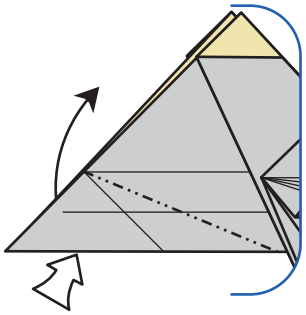
152. Fold the bottom edge up to the crease and unfold.



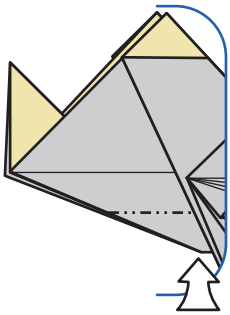
153. Fold the raw edges onto themselves and unfold.



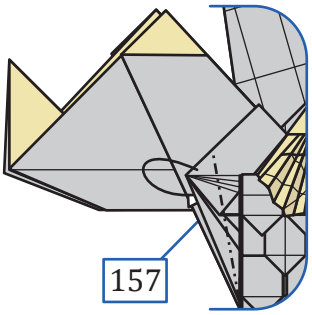
154. Fold an angle bisector and unfold.



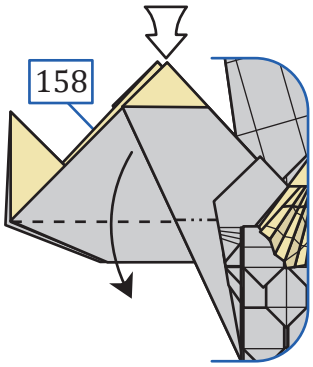
155. Reverse-fold the raw corner.



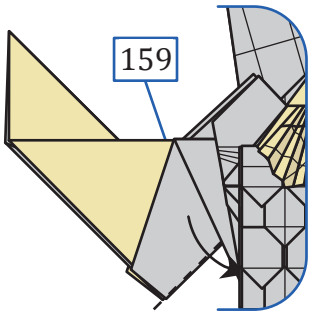
156. Closed-sink the edge.



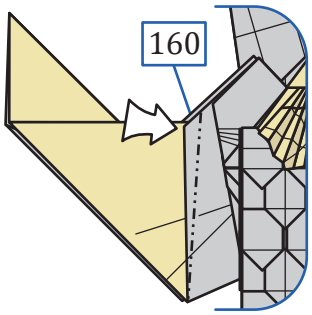
157. Mountain-fold the corner underneath. Repeat behind.



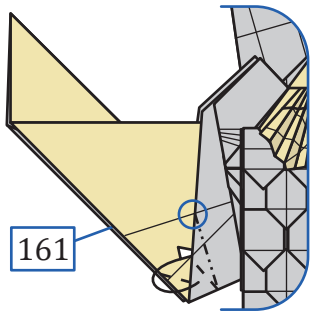
158. Reverse-fold the corners down. Repeat behind.



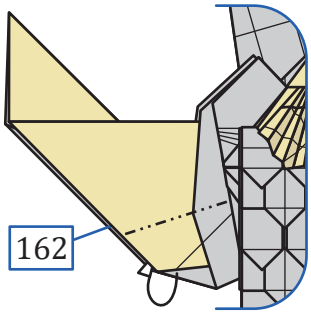
159. Valley-fold the flap down and to the right. Repeat behind.



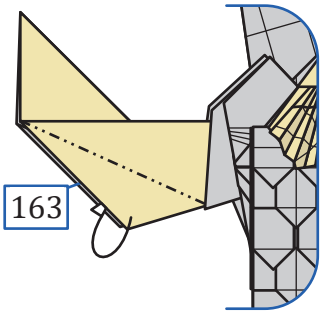
160. Make a very narrow reverse fold. Repeat behind, but make it slightly narrower than on the front.



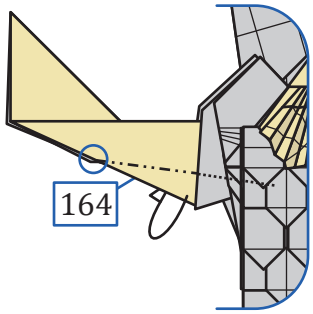
161. Swivel-fold some paper underneath. Repeat behind.



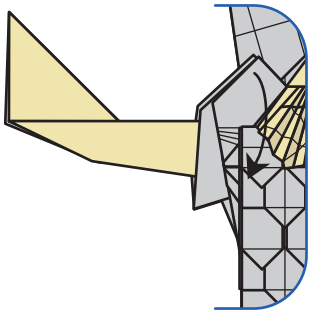
162. Lift the edge, fold it in along the angle bisector formed in step 146, then flatten the paper again. Repeat behind.



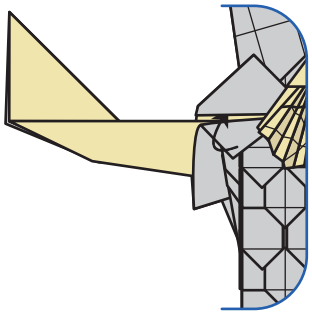
163. Mountain-fold the raw edge underneath along a new angle bisector. Repeat behind.



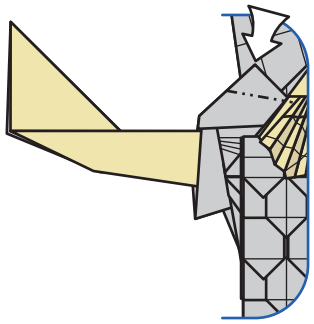
164. Mountain-fold some paper underneath. Repeat behind.



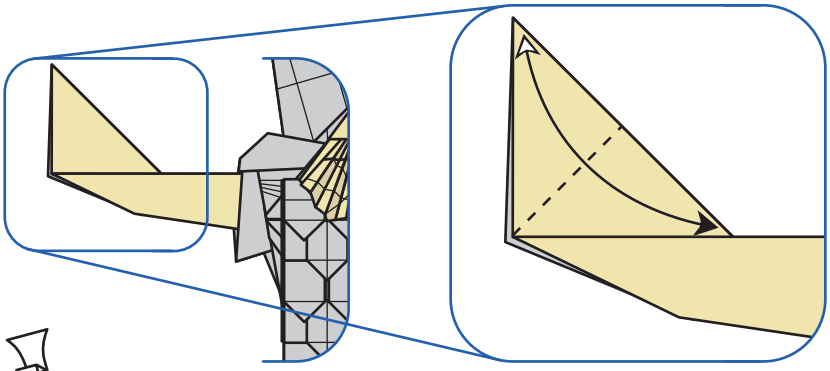
165. Gently bend the nearest corner at the shoulder down.



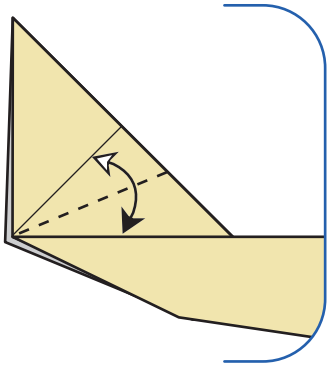
166. Tuck the corner into the pocket.



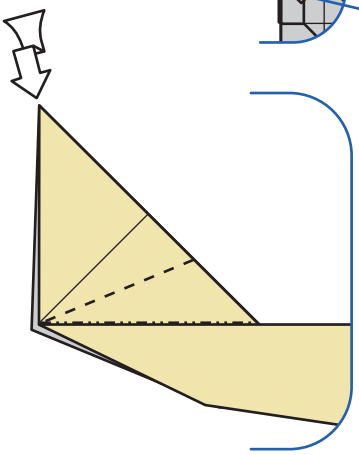
167. Reverse-fold the corner (or closed-sink if you're feeling brave).



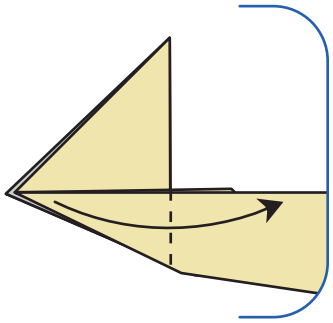
168. Fold and unfold.



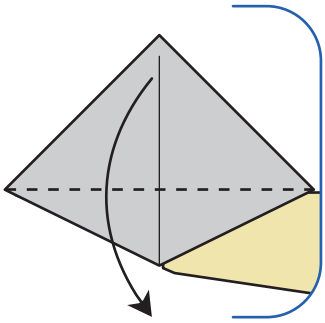
169. Fold an angle bisector and unfold.



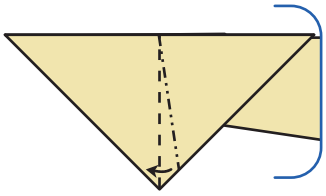
170. Reverse-fold in and out.



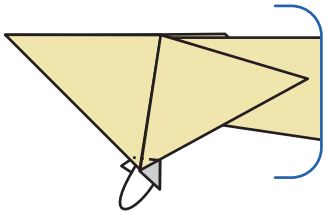
171. Fold one corner to the right.



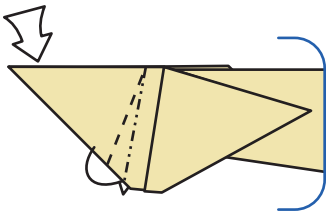
172. Fold the raw corner down.



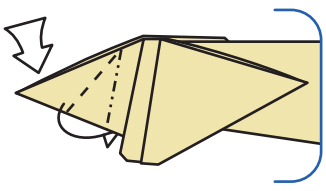
173. There are fewer exact references from this step onwards. Pleat the right half of the triangle on top of the left half.



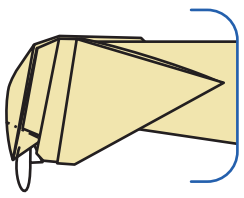
174. Mountain-fold the tip underneath.



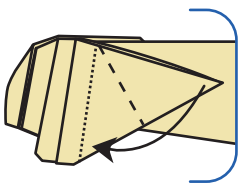
175. Pleat again – the mountain fold is parallel to the folded edge. Only fold the near layer – let it come towards you, separate from the far layers.



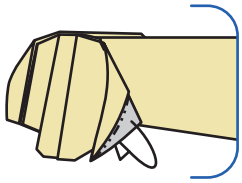
176. Pleat again – the mountain fold is parallel to the other folded edges, and the valley fold is an angle bisector.



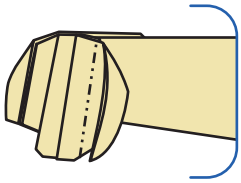
177. Mountain-fold the corner underneath.



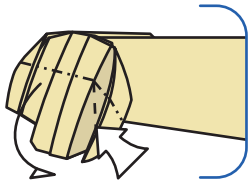
178. Fold the corner down and to the left.



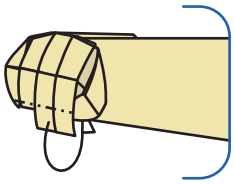
179. Mountain-fold the coloured edge underneath.



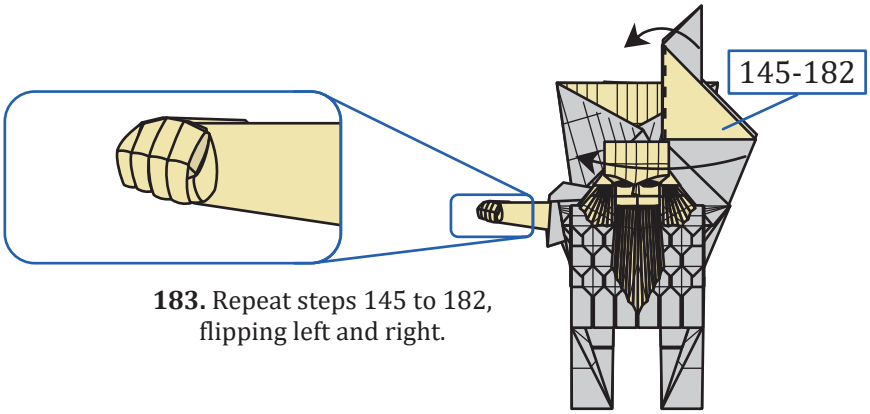
180. Pinch a mountain fold so that the paper on the right side becomes vertical.



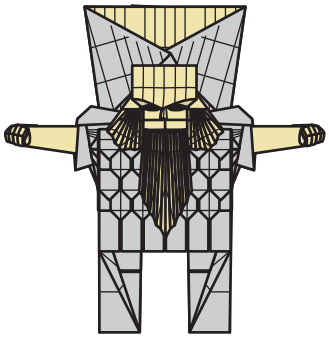
181. Mountain-fold along the midfinger knuckles – pleat in the vertical region, and curl the thumb inside the fist.



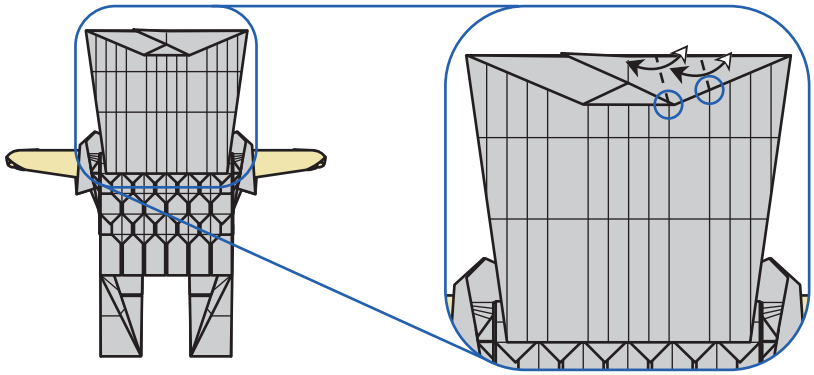
182. Mountain-fold the last segment of the fingers underneath to lock the paper in place and finish the fist.



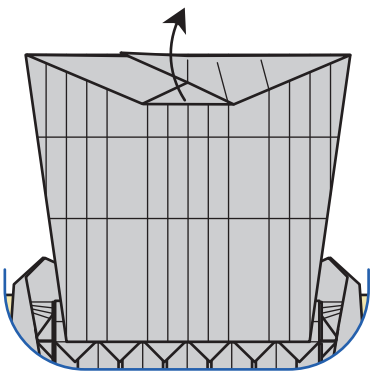
183. Repeat steps 145 to 182, flipping left and right.



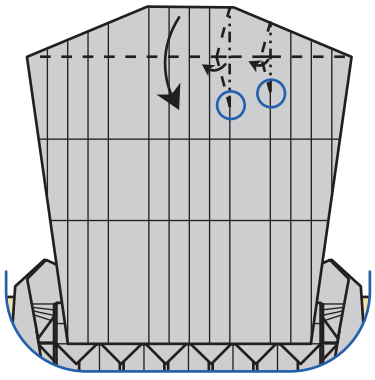
184. Turn the paper over.



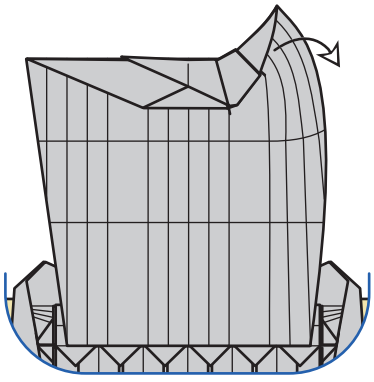
185. Fold and unfold two parallel creases, which are not quite vertical.



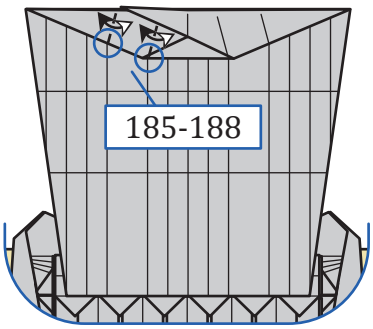
186. Fold the edge upwards.



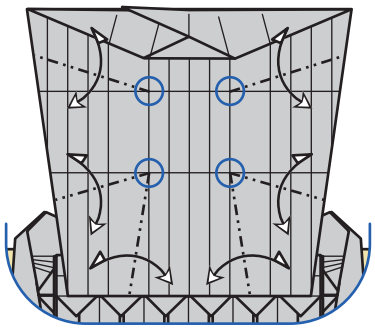
187. Fold the edge back down, but collapse using creases from step 185. The paper will be three-dimensional: two vertices will point towards you at the circled points.



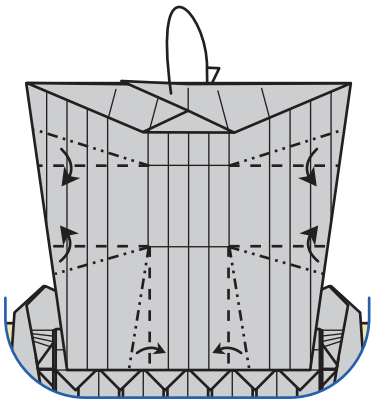
188. Unfold steps 186 and 187. You will need to refold these steps later.



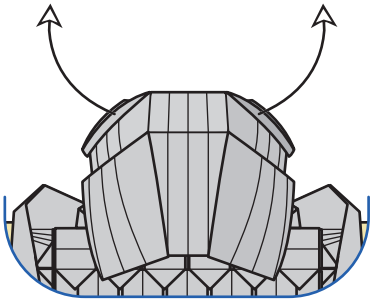
189. Repeat steps 185 to 188 on the left.



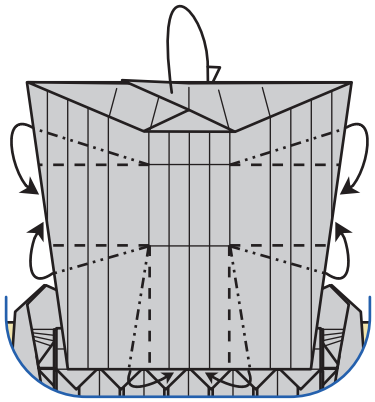
190. Pinch and unfold six **mountain folds**.



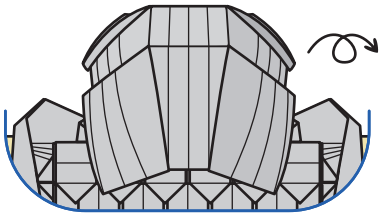
191. Pleat using the creases you just made.



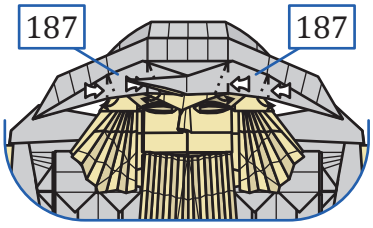
192. Unfold step 191.



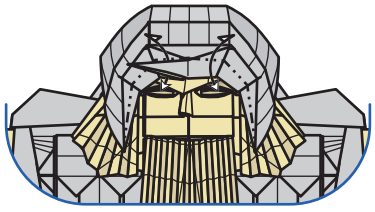
193. Refold step 191 but crimp instead of pleating, so that each mountain fold wraps around the edge on the reverse too. This is similar to step 187, and locks the shape of the helmet.



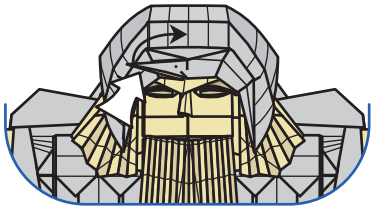
194. Turn the paper over.



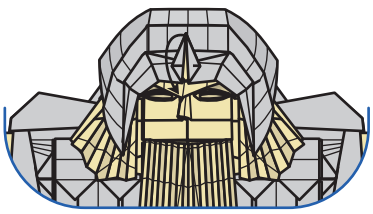
195. Refold step 187 on each side.



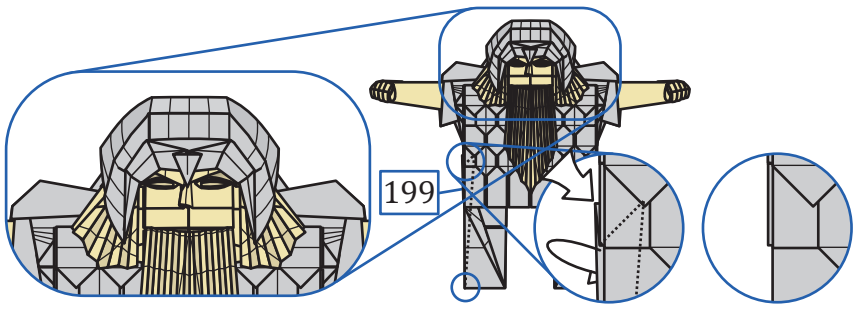
196. Pinch a mountain fold around the rim of the helmet.



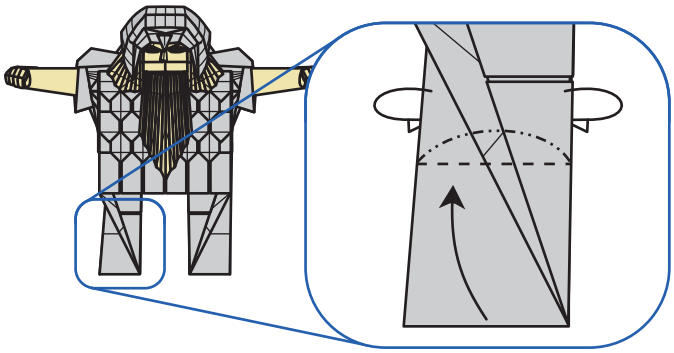
197. Squash-fold the raw corner upwards.



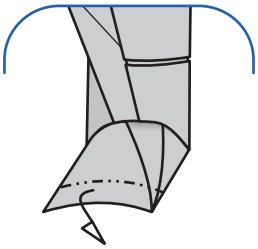
198. Fold the raw corner down.



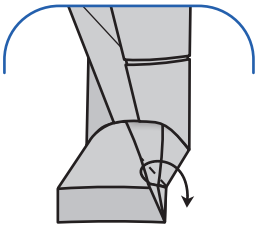
199. Swivel-fold an edge behind using hidden mountain folds. Repeat behind.



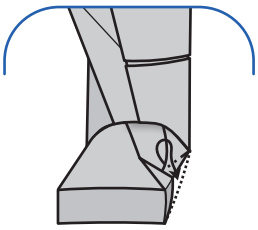
200. Fold the foot perpendicular to the body and curl the sides of the leg behind.



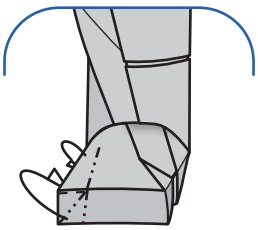
201. Fold the edge of the foot down.



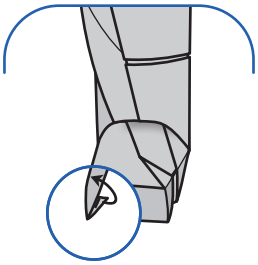
202. Wrap the left edge around.



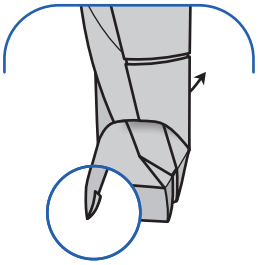
203. Pull the inner edge down to the same level as the previous fold.



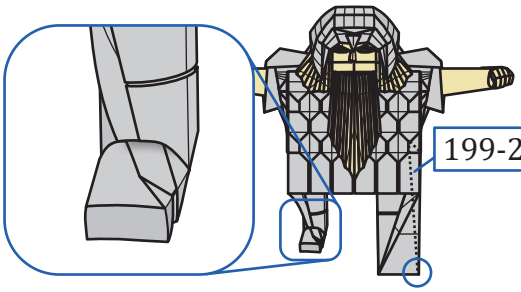
204. Pinch a diagonal mountain fold-line from the bottom left corner and fold it around the left side of the foot.



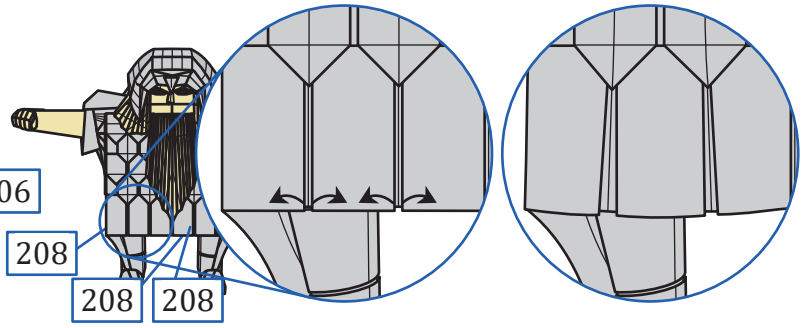
205. Tuck the tip inside to lock step 204 in place.



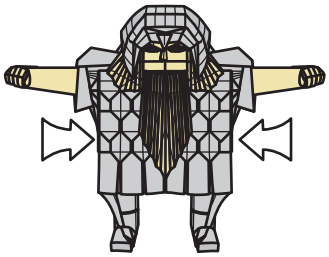
206. Pull some of the layers on the back half of the leg out to make the leg cylindrical.



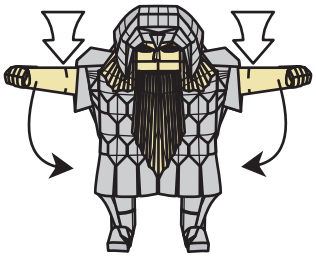
207. Repeat steps 199 to 206 on the other leg.



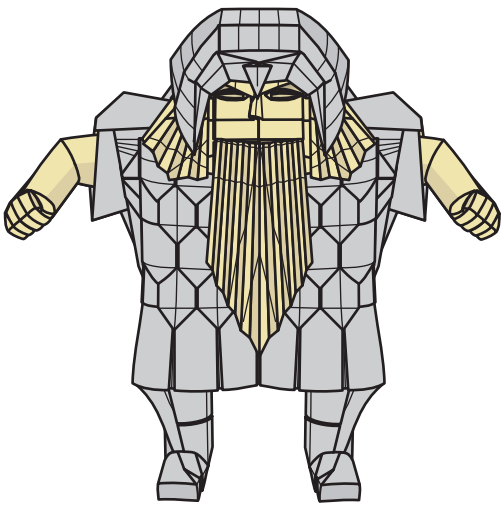
208. Carefully pull two pleats above the leg apart slightly. Repeat on the right, and twice behind.

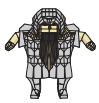


209. Push the sides together and make the torso more rounded.



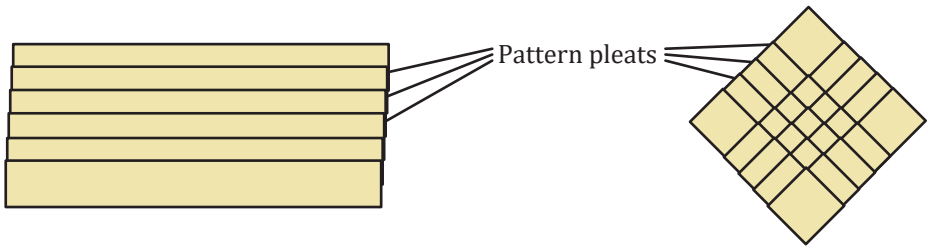
210. Shape the arms into an aggressive stance.





Tessellations

One of the most popular areas of origami involves making a geometric model by repeatedly folding the same sequence across the paper – these models are called **tessellations**. They are very good for practising precise folding because even small mistakes are often obvious in a model that should be uniform (and also because, for some reason, avid tessellators often find great joy in making their models as small as humanly possible).



Left: A very simple tessellation with pleats in one direction.
Right: A simple tessellation with pleats in two directions.

While many people enjoy folding tessellations in their own right, some of the most striking (and most complex) origami models are representational and have tessellations embedded in the design somewhere. For example, there's seemingly no end to the list of supercomplex origami dragons with scales. To distinguish standalone tessellations from tessellations embedded in representational models, I'll call standalone tessellations **patterns** (not to be confused with crease patterns) and call embedding tessellations on a model **patterning**. Each pleat which is part of the pattern is a **pattern pleat** (we'll see other types of pleats later in this chapter).

In this chapter, we'll see some methods for patterning a model. There are plenty of existing patterns, so we won't look at how to actually design them. Instead, we need to see how to integrate them into the rest of a design, which is often a much trickier challenge than the pattern itself. The most common patterns involve making several parallel pattern pleats in two directions, so we'll assume that the aim is to add rows of pleats like this to a model.

How do I pattern a model?

Pattern grafting

The easiest way to add a pattern to an existing model is by **pattern grafting**. This is done by examining the crease pattern and determining where the pattern pleats need to be. Before folding anything else, make the desired pleats in the paper so that they end up in the right region. Once the pleats have been folded, treat the patterned paper as a new sheet. Then fold the model from this new sheet.

Pattern grafting is easy, but it has a big problem (besides being time consuming). If any grafting, including pattern grafting, is only considered at the final stage of the design, then the locations of all of the other features are already decided. This means the parts of the pattern pleats that aren't being used in the patterned region are wasted, which makes inefficient use of the paper. Efficiency is often not the only criterion by which we should design, but it should be considered when pattern grafting because pleated regions are thick, uneven, and hard to fold. It's much better to look for solutions where the pleats are factored into the design from the start.

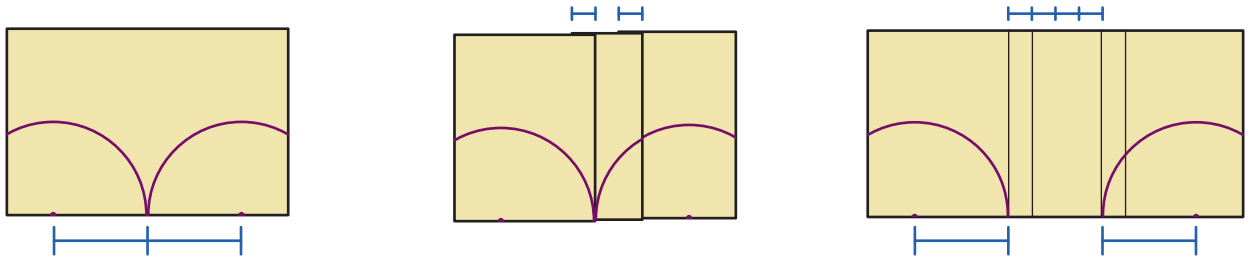
Incorporated pleats

Pleats which aren't grafted are **incorporated pleats**, and there are multiple ways to make them. Incorporated pleats are not inherently efficient – it depends on the implementation. In the worst-case scenario, incorporated pleats end up using just as much paper as grafted pleats and make folding the model much more complicated.

The Dwarf Brawler incorporates pleats in three different ways. Let's look at each of these in turn, examining why they are useful in their respective situations.

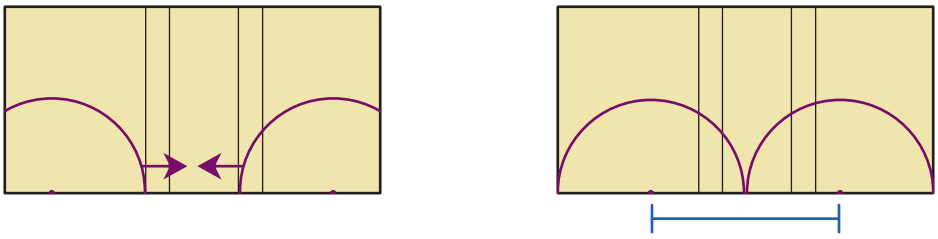
Stretches

We'll start by looking at two edge flaps with pleats between them, which is common in a model with grafted pattern pleats. The diagram below shows how adding pleats increases the distance between flaps. Quantitatively, the extra distance is twice the sum of the pleat widths.



Left: Two edge flaps in an ungrafted model.
Centre: Pleats are grafted between the two flaps.
Right: After unfolding the pleats, we can see the actual distance between the flap tips on the paper.

It looks like we should be able to move the flaps closer together to fill this new gap (because to make efficient designs, we want to squish features as close together as we can). But can we actually use this space, and what does this look like when folded?

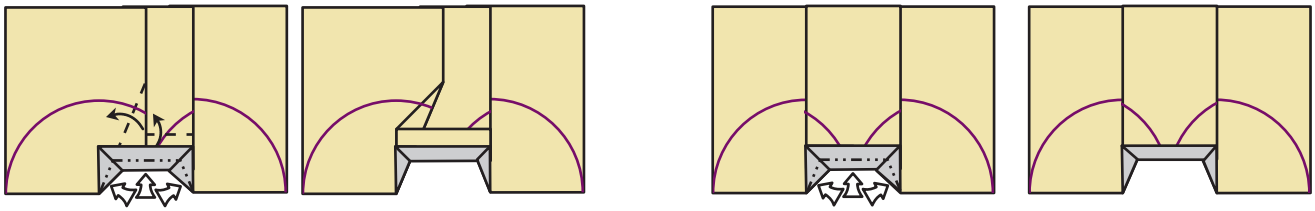


We can move the flaps towards each other until they touch. Will this work?

It depends on what we're using the flaps for. Suppose we want to keep the flap tips exactly where they are on the paper after pleating. Then we can fold the raw edge up and stretch the pleats apart, as shown on the left below. After this stretch, the shortest distance between the flap tips (without leaving the paper) is along the red path shown below. Its length is only about 60% of the theoretical maximum distance, i.e. the actual distance between the flap tips in the unfolded paper.

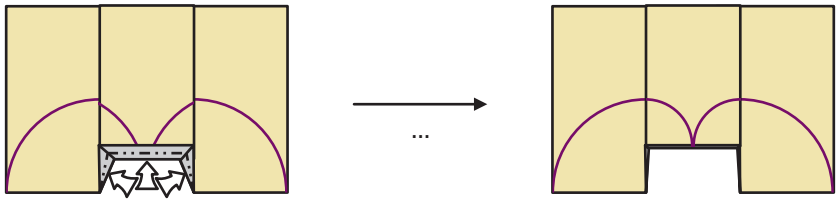
Stretching the pleats: this increases the distance between flap tips by creating negative space.

It would be great if we could get this distance up to 100%, but is this possible? We can perform another stretch to increase the gap. But this stretch is quite complicated. We can make things easier for ourselves by folding one of the pleats to the left first. These options are both shown below.



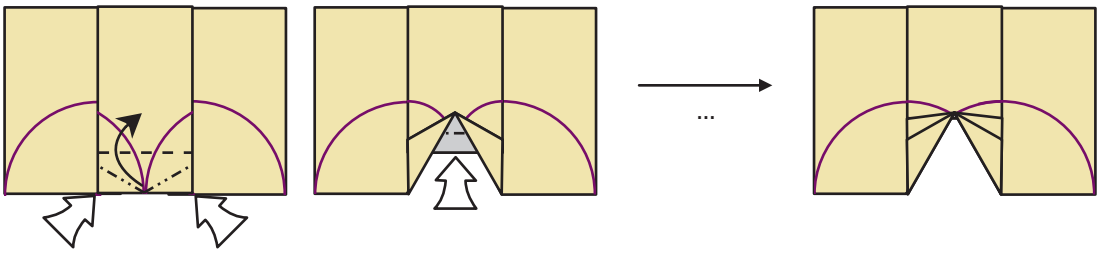
Left: A more complicated stretch. Right: Creating the same negative space, but with a slight readjustment to the left pleat so that the paper is symmetric.

If we continue with the simpler stretch on the right above, we can keep performing increasingly smaller stretches. The theoretical limit of this process is a shape with a rectangular cutout whose upper boundary is the raw edge. With enough folding, we can get closer and closer to this shape and, in doing so, get closer and closer to 100% of the theoretical maximum distance.



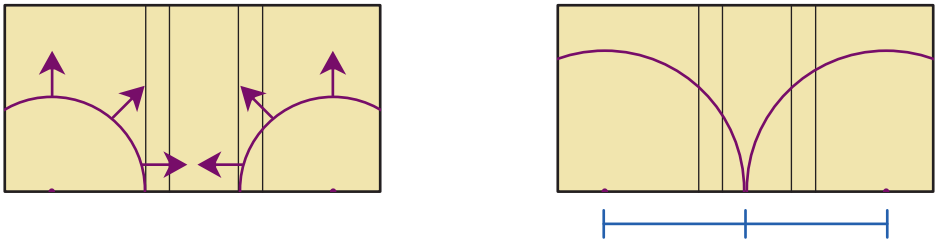
Given the initial stretch, the theoretical limit is a rectangle.

But we might not want a rectangular cutout, so we'll consider another possibility for the initial stretch, where the raw edge forms the top part of an equilateral triangle. With enough folding, we can perform more stretches so that the negative space gets arbitrarily close to the equilateral triangle. I'll state here (without proof) that this works in general: given any initial stretch there is a sequence of further stretches whose limit creates a cutout in the exact shape of the raw edge of the initial stretch. In fact, this isn't limited to parallel pleats perpendicular to the raw edge, but those are the examples we'll use here.



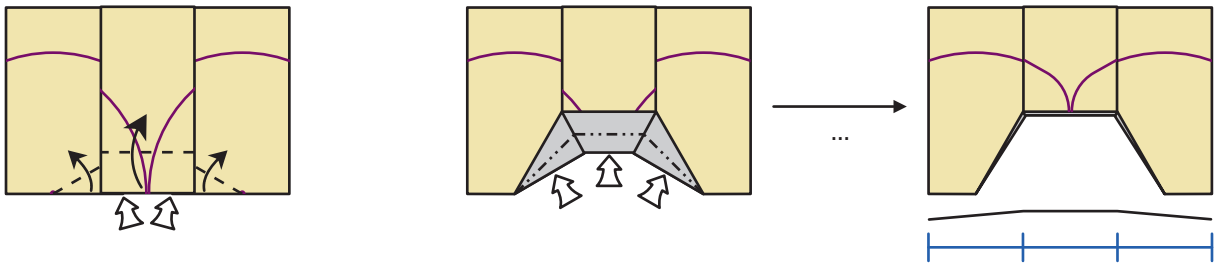
Given any initial stretch, we can create a cutout arbitrarily close to the shape of the raw edge.

We'll try one more possibility: instead of moving the flaps closer together after adding the pleats, we'll try expanding the flaps to fill the gap instead.



Expanding the flaps until they touch.

Let's pleat the paper again and try a different stretch. (We'll learn from the previous investigation and pleat symmetrically this time.) And this time, we'll create the top half of a regular hexagon.

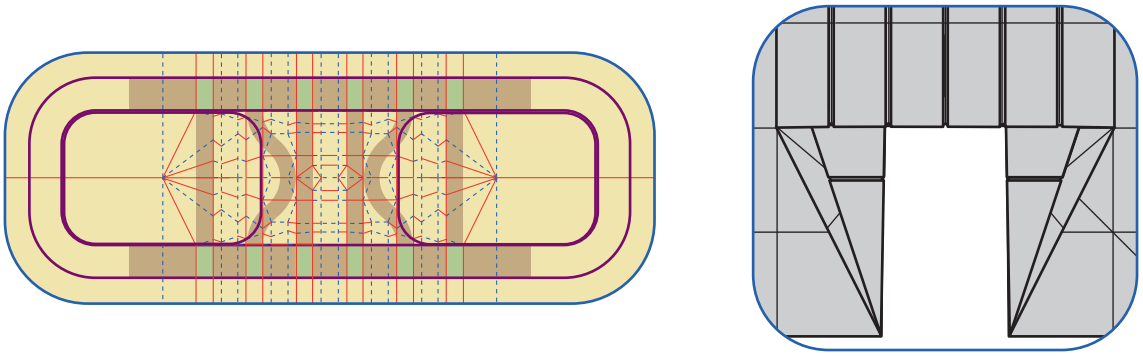


As before, the limit of stretches creates negative space whose boundary is along the raw edge. Observe that the total distance between flap tips after stretching is the same as the distance on the unfolded paper shown on the previous page.

There are countless other possibilities with just the pleat configuration shown here: I've only shown some of the simplest options.

The Dwarf Brawler contains a stretch to separate the legs – see steps 51 to 63. A stretch is a good choice for the legs for three reasons:

- The legs need to be horizontally separated (in other words, the base isn't uniaxial); stretches maintain this gap naturally by creating an area of negative space, as with the three examples above.
- The pleats propagate across the paper away from the legs in both directions, so folding is easiest if we keep and use the pleats, rather than altering or terminating them (see the next two sections).
- Although there are some regions of the arrangement that are very constrained, there's plenty of horizontal wiggle room for the leg flaps in the centre of the paper (see the left image below). This means that for each individual pleat, we have the choice to stretch it or keep it folded, as is convenient. Other methods don't have such flexibility and are therefore more complex to fold.



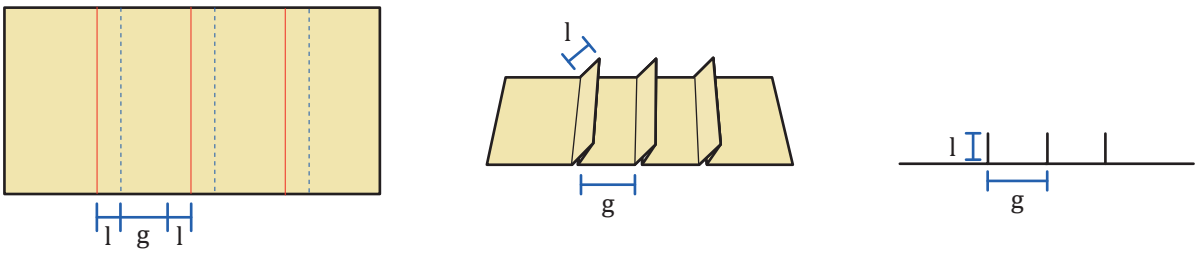
Crease pattern and folded base showing the stretch to create the legs of the Dwarf Brawler.

Pleat Conversion

Stretches are relatively easy because they leave the pleats unaltered, but this limits their usefulness. We'd have a lot more options if we could change the pleats by transforming them so they have different widths or directions. I call these types of transformations **pleat converters**.

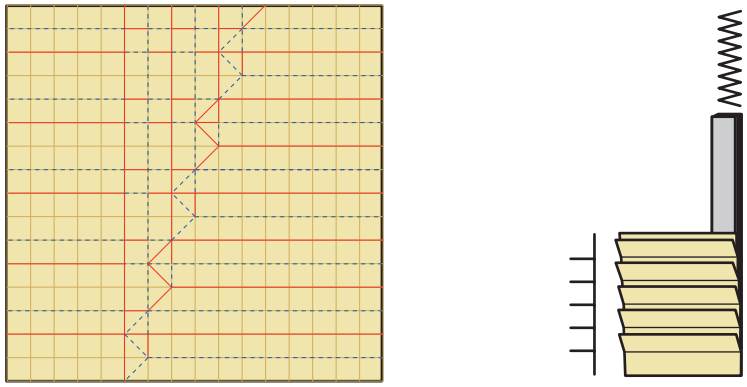
Pleat converters are structured and technical. They are prevalent in box-pleated designs because using a grid provides valuable references for the exact folds to be used.

We'll look at the cross-section of pleats and represent this as a stick figure. This stick figure has regularly spaced leaf edges emanating from a single stem. We call such a stick figure a **comb**. We'll quantify combs with two variables: ***l***, the length of each leaf edge (the width of each pleat) and ***g***, the gap between leaf edges (the space between pleats). We'll call a particular comb where these values are known an **l,g-comb**. For example, the pleated structure at the top of the next page is a 1,2-comb. Note that in some circumstances, what matters is only the ratio l/g, but here we will need to distinguish between two different combs even when this ratio is the same.



Crease pattern, folded model and stick figure of a 1,2-comb (l=1, g=2). Note that the distance between peaks on the crease pattern is 4: in general this distance is $2l+g$.

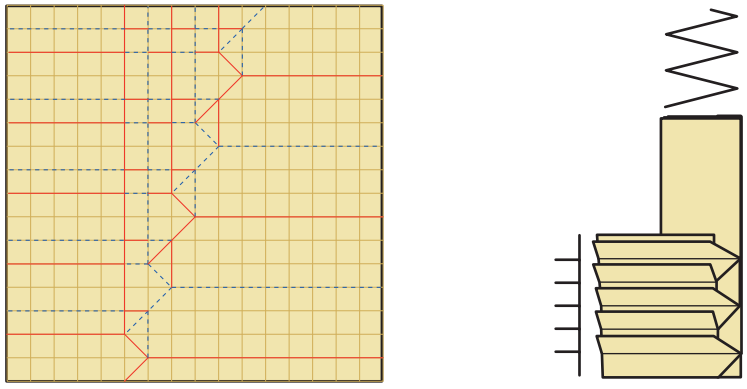
One of the most common examples of pleat converters turns 1,1-combs into 1,0-combs (pleats with no gaps) by folding the new pleats away at a 90° angle. This means they run along the boundary of the patterned area rather than being perpendicular to it. One crease pattern showing how to do this is below.



Crease pattern and folded model showing a 1,1-comb being converted into a 1,0-comb.

A 1,0-comb (or indeed any x,0-comb) is just an alternating sequence of equally-spaced mountain and valley folds. This structure occurs frequently in complex origami: you can see large sections like this in several crease patterns in this book. This means that pleat converters involving an x,0-comb are very useful because they can be most easily integrated with other sections of a crease pattern. In particular, the transformation between an x,0-comb and a y,0-comb is common enough that it has its own name – a **level shifter**. (Though note that level shifters can appear in other forms.)

There's actually a simple modification to the crease pattern above which converts a 1,1-comb into a 3,0-comb. Used in reverse, it's an effective way to make small pleats in one go (rather than using two separate pleat conversions, which is less efficient). However, I can't recall ever seeing this implemented in a model. Do experiment with it for yourself to see if you can find a good use for it.

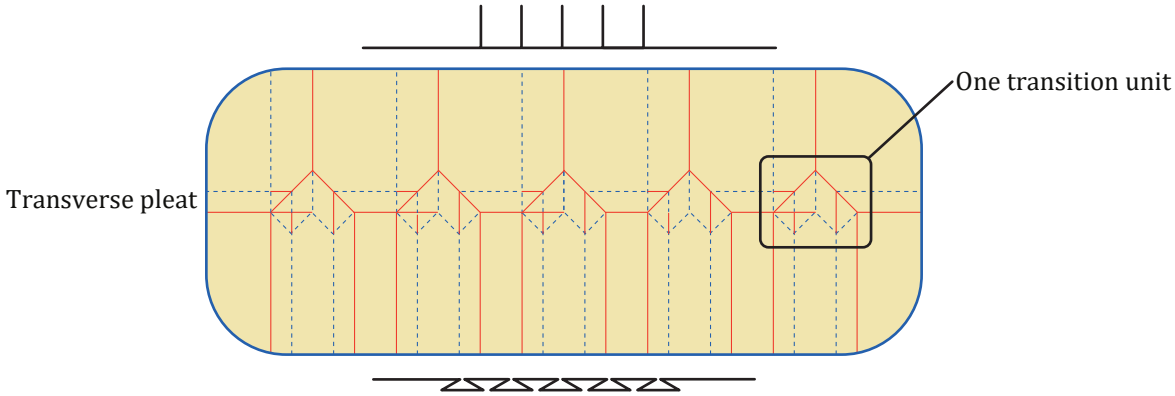


Crease pattern and folded model showing a 1,1-comb being converted into a 3,0-comb.

Although they are easy to fold, there is a reasonable amount of paper loss with the previous two pleat converters. The crease patterns contain vertical pleats in the centre which separate the left and right regions along the upper raw edge, but the left and right regions don't need to be separated. This means that the paper in these pleats is wasted, and this problem gets worse the more pleats there are which need converting. (Lossless versions can be constructed, but in general the creases do not lie on a grid. An exploration of this topic quickly becomes very technical, so deserves separate attention and shouldn't be shoehorned in here.)

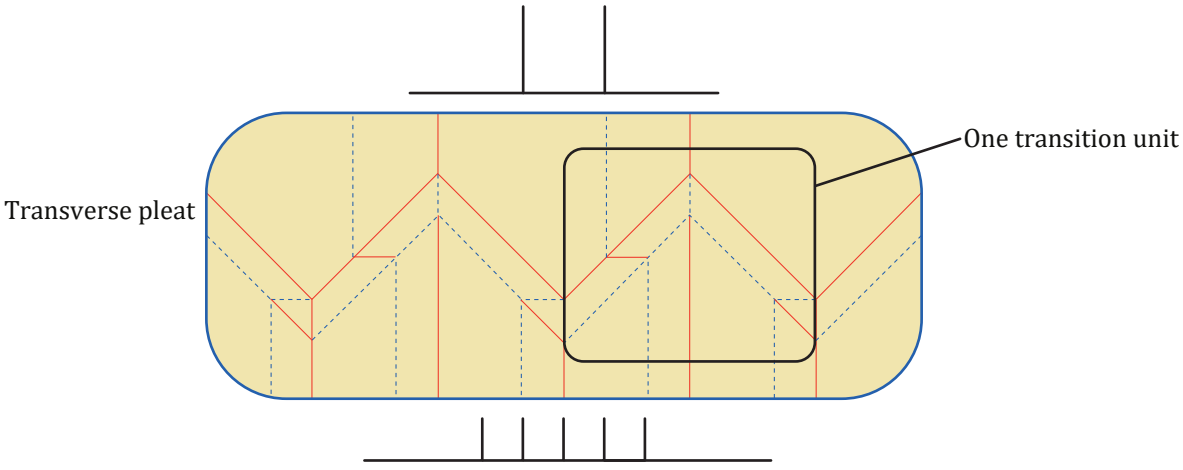
There is a similar cost when making two combs which point in the same direction: one small, new pleat that crosses the pleats of the comb, typically at a right angle. I'll call this pleat a **transverse pleat**, and the smallest repeating crease pattern along the transverse pleat is called a **transition unit** (see the diagram below). The exact size of the transverse pleat depends on the combs being converted, but normally the minimum required width is less than the larger of the two comb lengths. The width of the transverse pleat doesn't depend on the size of the patterned area; therefore, when used on a patterned region with many small pattern pleats, the amount of extra paper needed to make this pleat converter is small compared with the previous examples.

The Dwarf Brawler contains two different pleat converters. The first converts the pleats at the top of the armour (which isn't a comb) into a 1,1-comb. This is folded in steps 88 to 95.



A simplified crease pattern for the top of the armour of the Dwarf Brawler. The vertical pattern pleats at the bottom are the armour, the vertical pattern pleats at the top (a 1,1-comb) lead to the head, and the horizontal transverse pleat contains the paper lost in the conversion.

The other use of a pleat converter in the Dwarf Brawler has the effect of enlarging a 1,1-comb into a 2,2-comb. This can be seen in steps 96 to 100.



A simplified crease pattern for the bottom of the Helmet of the Dwarf Brawler. The transverse pleat is a zigzag in this case.

These two pleat converters are used to transition between the top of the armour and the head. They are a sensible choice here because we need larger pleats to make the face and the rim of the helmet than we do for the pleats in the armour.

Combining pleat converters

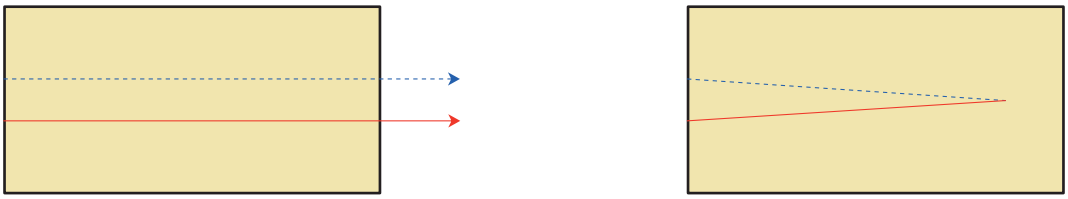
Pleat converters are a nifty gadget in the origami toolbox and can be applied in succession to build up even more tools. For example, the crease pattern above could be used to convert a 2,2-comb into a 4,4-comb, which could then be converted into an 8,8-comb etc., doubling each time. This useful type of enlargement occurs in any conversion between combs with the same l/g ratio.

One note about pleat converters: they require combs or other regular, pleated structures, which reduces their versatility. This is in contrast to the other two methods in this chapter, which don't require any regularity in the pleats – the width of each pleat and the gaps between them could all be different (in fact, they don't even require parallel pleats at all).

Pleat Termination

If we only want pattern pleats in a particular region, then it makes sense to find ways to terminate pleats at one or both ends. This will entirely remove the problem of pleats extending beyond their intended domain.

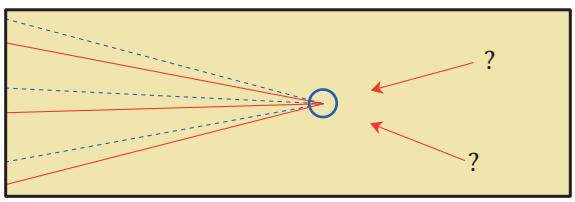
The reason pleats extend indefinitely is because they are parallel. As noted at the beginning of the chapter, this isn't always the case and actually gives a compelling reason to not use parallel pleats: non-parallel lines always meet. Therefore, if we can alter either the mountain or valley (or both) of a pleat so that they touch, the pleat will terminate.



Lines meet if and only if they aren't parallel.

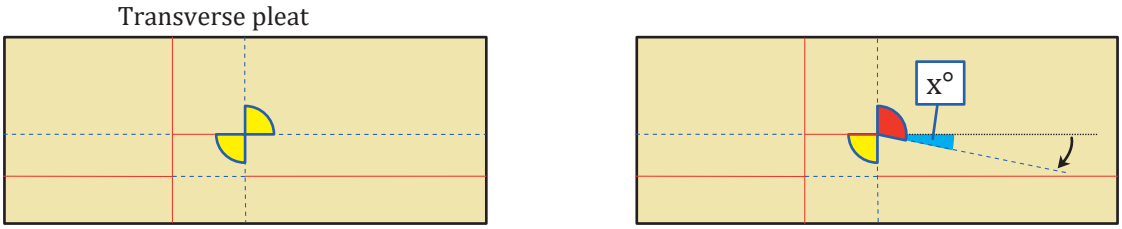
Radial pleat termination

One rather satisfying way of doing this is to make several pleats converge at a single point. I'll call this point the **termination point** for the set of pleats. Each pleat contributes one valley and one mountain to the creases at the termination point, but it's a well-known fact that the difference between the number of valleys and the number of mountains is always two in flat-foldable origami (Maekawa's Theorem). This means there must be some other creases at the termination point if we want to region to lie flat, so it's natural to use an existing point in the crease pattern as a termination point rather than creating a new vertex.



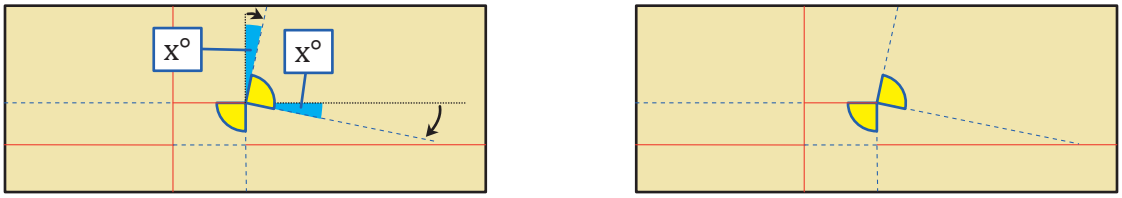
A termination point: there must be at least two more creases around this vertex.

But how do we alter the angle of our pleats to begin with? As with pleat converters, this requires a new transverse pleat. Let's try an example with one pleat and see if we can alter the angle of just one of the fold-lines. In the diagram below on the left, take note of the vertex in the centre, where a vertical transverse pleat crosses a horizontal pleat – both yellow angles are 90°. If we try to rotate the horizontal valley fold on the right by itself, the paper doesn't lie flat. This is because the sum of alternate angles around any flat-foldable vertex must be 180° (Kawasaki's Theorem).



Left: Both yellow angles are each 90°. Right: If the valley fold on the right rotates x° clockwise, then the red angle is x° too big, so the pattern won't fold flat.

To resolve this, at least one of the vertical valleys must rotate too. In the example below, the upper valley rotates, allowing the paper to fold flat.

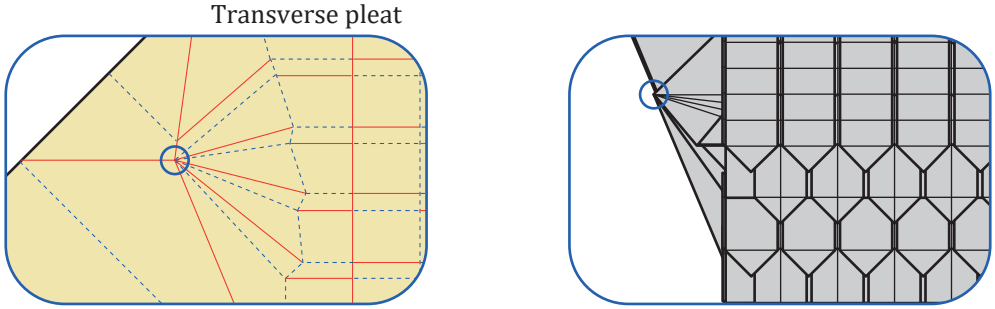


Left: The valley at the top rotates x° clockwise too. Right: The central vertex is flat-foldable.

The same change in angle occurs for each pleat, which means the transverse pleat will wiggle across the pleats and will not align nicely with other existing areas of the crease pattern (unless the angle of rotation is chosen very carefully).

In the Dwarf Brawler, radial pleat termination is used to terminate the pleats on the sides of the armour and can be seen in steps 66 to 69. This technique is appropriate in this section of the model because:

- These sections transition between the box-pleated armour where the pleats are used and the 22.5°-geometry arms, where we don't want any pleats.
- The armour is near the raw edge, so the resulting creases, which are at an unusual angle, can be immediately sent off the paper so as not to interfere with the rest of the crease pattern.
- There are only four pleats used here. Radial pleat termination should be limited to a small number of pleats because a large number of narrow pleats will create a lot of stress at the termination point (i.e. there's a relatively high chance of rip).

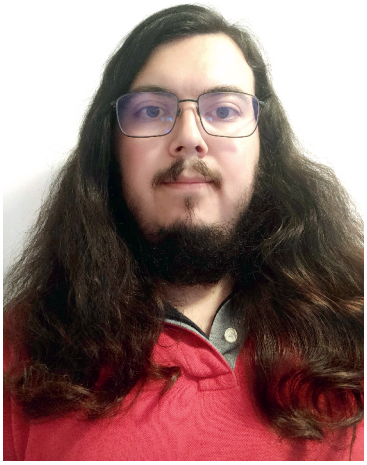


A simplified crease pattern and folded model of the left side of the Dwarf Brawler's armour. The termination point is circled in both images. Note the zigzag valley of the transverse pleat in the crease pattern.

Radial pleat termination is perhaps the trickiest of the three techniques in this chapter to fold accurately and is, unsurprisingly, also the least common. But it has a lot of flexibility and can create more organic forms than methods limited to pure box-pleating. Explore this technique for yourself and use it in your own origami designs to make a patterned model with a fresh flavour.

Contributors

Florian Videau



Florian's gone above and beyond with testing the diagrams for this book, and I'm hugely grateful for the time he's put in to find all of my mistakes! He's given some quick advice for checking diagrams, which is not just useful for diagrammers but for anyone trying to follow step-by-step diagrams:

"As a software engineer, I love understanding how things work, and I know how important clear and detailed instructions are.

When folding a model from diagrams, I always look at three things:

- The arrows and creases
- The text explaining the step (if it is in a language I can understand)
- The next image, in order to know the expected result

These should all match; otherwise, there is something wrong. In draft diagrams, I try to see which one of the three does not agree with the other two to understand what should be fixed.

Sometimes those three elements do align, but once I have the paper in hand, I have to spend some time testing and tinkering to understand what should be done, which, for me, indicates a lack of clarity in the instructions, and I try to see how to make them easier to understand."

Michael Nguyễn

Michael Nguyễn is a communication designer and infographic artist from Germany who discovered his passion for origami at the onset of the Covid pandemic. Specializing in reinterpreting and shaping humanoid origami, he has received multiple nominations and prizes at the Joisel Awards in the "Figurative Interpretation" category and recently held his first artist exhibition in Berlin, as well as organizing online origami workshops with his fellow peers.

Michael explores various methods of introducing new details and textures through freefolding, effectively rearranging entire structural sections of the existing crease pattern. This approach yields results that diverge significantly from the original design, despite utilizing the same base. Drawing inspiration from the sculptural richness of works by Eric Joisel, Kei Watanabe, and Giang Dinh, Michael employs sculptural techniques to heighten his creations with realism, breathing life and drama into paper.

His fascination lies in realizing the intersection between origami and the expressiveness of human emotion and storytelling within the realms of history, culture, and religion. Having recently graduated with his bachelor project focused on origami terminology, Michael aims to connect with people through origami in meaningful ways and encourage the wider public to look beyond traditional perceptions of origami folding.

Instagram: @mayuncchigami

I'm incredibly grateful to everyone who has spent time testing the diagrams in this book, and it's always very inspiring to see their creative interpretations. For example, I love the extra hearts which Sampreet Manna has added using the spare raw corners in Psyche, the four-legged pose of Goar Sanchez's Hydra, and the almost alien-like position of Gaurav Athavale's Spider.

Rather than keeping these photos to myself, this colourful page is here to showcase the extraordinary talent of some of the folders who have made this book possible. Thank you to you all.

Javier Hernández Ahuat

Goar Sanchez

Sampreet Manna

Romain Bontemps

Gaurav Athavale

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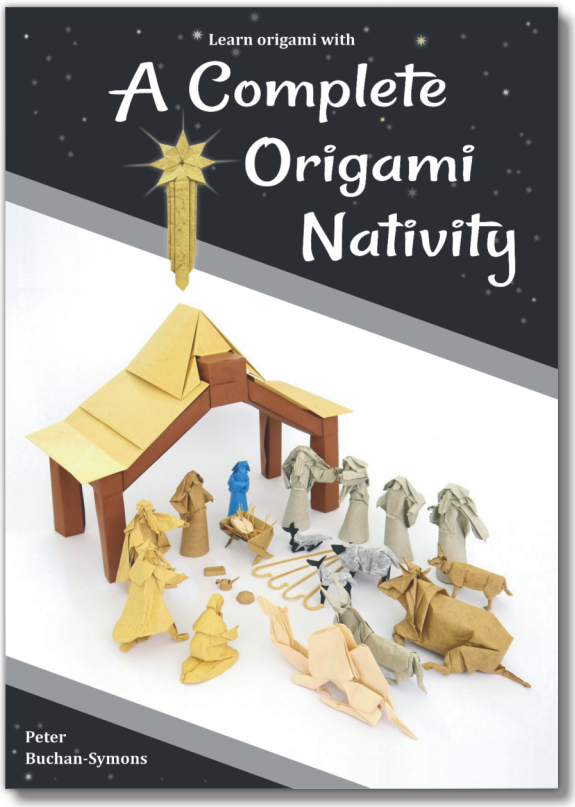

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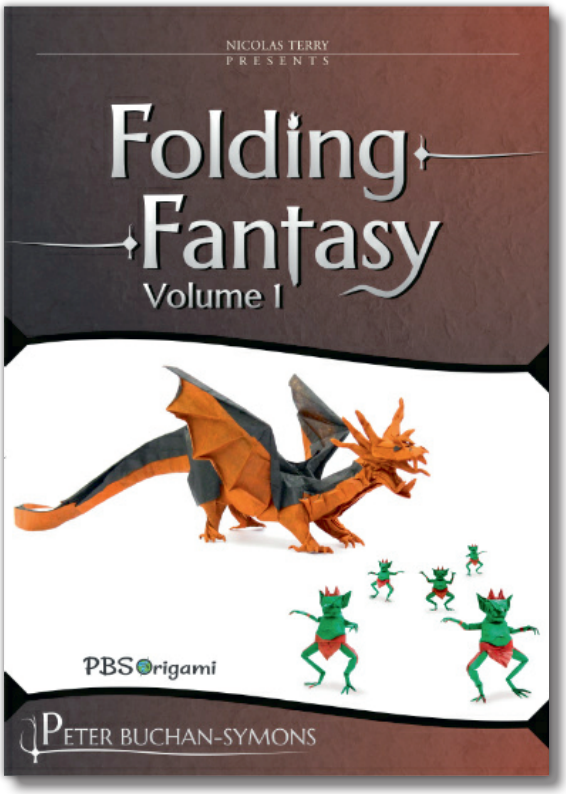

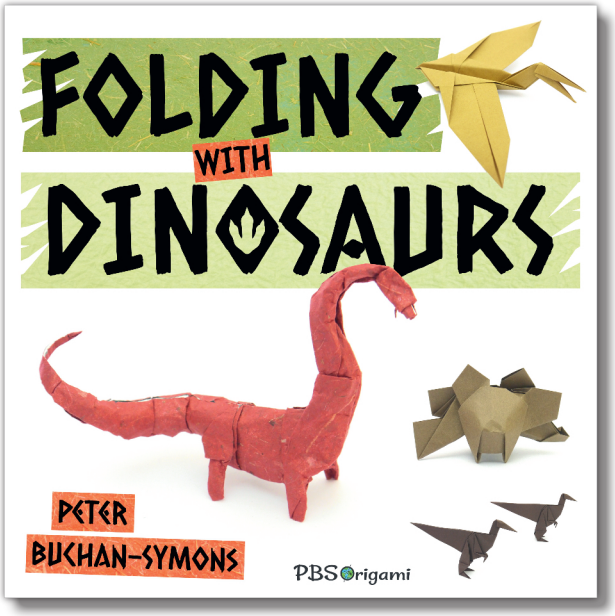

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FLORIAN VIDEAU MICHAEL NGUYỄN

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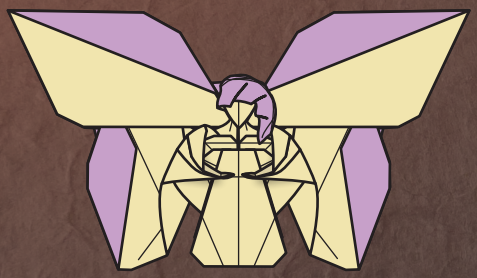

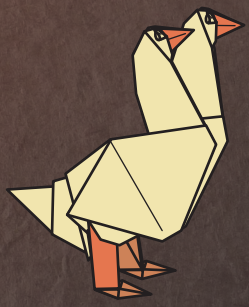

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Folding Fantasy

Volume 2

PETER BUCHAN-SYMONS

书中文章的中文翻译

由于我们不懂这门语言，因此在提供和进行翻译时，DeepL，我们不进行校对或编辑。如果您希望提出更正或改进建议，以丰富译文内容，让更多人受益，请通过以下地址与我们联系：contact@origami-shop.com。

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INTRODUCTION

这本书不仅仅是另一本为你的折纸清单打钩的复杂模型目录。我不希望为你提供越来越高的难度，而是想让你发现折纸设计师的感觉。

这种感觉在 "设计背后 "章节中尤为明显。与第 1 卷相比，我试图介绍更广泛的主题。其中既有技术性的设计方法，包括新折纸理论的发展，也有设计模型过程中的高低起伏（因此不一定提供实用的设计建议）。因此，虽然这些主题可能看起来并不直接相关，但这正是重点所在：展示我作为设计师的各种经历。

我希望你在折叠模型时能感受到这种多样性。有些是通过 CP（Caneva de Pli）有条不紊地规划的，在我开始尝试用纸之前就已经完全成型了。例如，"九头蛇 "有一个严格的结构，在早期阶段有一个寻找参照物的技术流程。

而像 "有翼雌鹿 "这样的模型，则是以一种更有趣的方式构思出来的，以主题的感觉和纸张的自然限制为指导。通常，我很想通过找到明确的参照物来简化这类图案，但我决定不这样做，因为这会掩盖设计创作的真相。我希望通过这些反复出现的不知道到底该折叠在哪里的时刻，你能学会欣赏这种真实性。

值得一提的是，虽然这是一个系列的第二卷，但你并不需要折叠过《折叠幻想：第一卷》中的设计。我已经尽最大努力使 "设计背后 "章节中的主题本身也易于理解。不过，我也会提及和扩展已经讨论过的观点，所以如果你已经阅读过第 1 卷中的信息，就能从这些章节中获得最大的收获。无论你是否是本系列的新读者，我都希望你能喜欢这第二套模型，并能加深你对折纸设计的了解；你不仅可以通过阅读和吸收这里的信息，还可以通过自己的实验来发现自己的秘密。

请注意

书中特意没有解释图解符号的术语，因为这些信息可以在《折纸幻想：第 1 卷》中找到，所有有能力制作该书中模型的折纸爱好者都应该已经熟悉了。

不过，我已经在 pbsorigami.co.uk 网站上免费提供了这些信息，如果你想重温一下记忆的话。

Wonky Gravestone

我希望你能勇敢地使用这个图案。我特意没有提供第 1、11 或 15 步的参考，也没有提供褶皱图案。我让你们自己去判断！
这样，您就可以在完全安全的情况下发挥您的创造力，因为在这些图示的模糊区域内的任何折叠都会产生合适的最终模型。更重要的是，用这种方法制作一个独特的、外观破旧的墓碑要比用死板的（更长的）折叠顺序容易得多。

Two-Headed Goose

我特意将这个模型与我之前在 "简单的春天折纸"（Easy Springtime Origami）中的鹅模型（经典的单头鹅）做成了相同的风格：尽管底层结构完全不同，但每块挡板的形状都是一样的。

如果想让模型更简单，可以省略最难的步骤：26 至 27、31 至 37 和 39 至 40。

Winged Doe

有翼鹿是单面图案的一个例子。因此，与其他具有类似步骤数的图案相比，它相对较快，因为（几乎）没有 "后面重复 "的步骤。

从第 15 步开始，大多数新的折叠都没有参照物。不要指望你第一次尝试这个图案就能做到完美。只要多折叠几次，了解自己的折叠偏好，看看随着时间的推移会有怎样的进步。

您还可以将此模型改编成其他有翅膀的生物，例如制作休息的埙。

Gnome

要折出一个匀称的折纸人脸是比较困难的。因此，这里有一个屡试不爽的技巧（针对懒惰的设计师？在这里，这个小矮人的帽子遮住了他的眼睛和耳朵，胡子遮住了他的下巴、脖子和肩膀。

这个地精的底座是我最喜欢的之一。它有几个吸引人的特点，比如熟悉的子结构、长短襟翼的组合、一条河、大量的边框襟翼以及用于换色的额外纸张。试着用这个模板制作你自己的模板（只使用步骤 1 至 8、13 至 21 和 29 至 31，以避免使用侏儒特有的步骤）。

Nettle

荨麻的主要特征是叶子呈锯齿状（除非您想在纸上添加倒钩，否则折起来会很不舒服）。

如果您想制作一种普通植物，也可以跳过第 77 和 78 步，获得更圆润的叶子。

Cutethulhu

克苏鲁是 H. P. 洛夫克拉夫特的《克苏鲁的呼唤》中的巨型生物（幸好是虚构的）。他依稀是人形，但长着龙的翅膀，更具有象征意义的是，他的头是章鱼。这种生物在许多其他恐怖小说作品中都得到了普及。

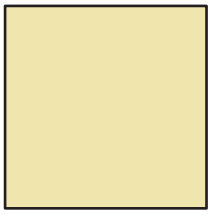
这幅画的灵感来自一幅街头艺术作品，画中的克苏鲁远没有人们想象中的那么邪恶。

植物干旱

花朵是最受欢迎的折纸模型之一，原因有很多。它们（通常）是对称的，这使它们易于设计和折叠，它们很容易被识别为一种花（即使没有代表实际的物种），而且它们色彩艳丽，极具吸引力。但是，在同一张纸上还能折出植物其他部分的花朵折纸却相对较少。

完整的 "折纸植物之所以罕见，原因恰恰与花朵常见的原因相反。它们都是野生的，通常是不对称的，往往不显眼，而且无一例外都是平淡无奇的绿色。但我要探讨的是折纸植物缺乏的一个更深层次的、折纸特有的原因。

正方形是什么形状？

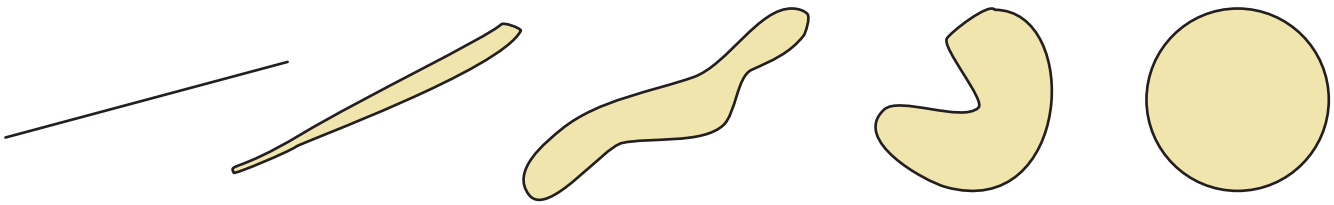


这似乎是个愚蠢的问题，如果是问折纸爱好者，可能就更愚蠢了，因为在所有人群中，他们是最熟悉正方形的。

但我并不是在寻找一个涉及直角、平行线或边长的技术性答案。我站在后面，从远处看一个正方形。从一个更不利的角度来看，我们会忽略细节，发现也许是最基本的特性：它是一个质量。谈论这种不精确的属性很有用，因为它适用于除正方形以外的许多形状，包括圆形、正多边形和上图中的矩形（上图中的形状不是正方形，因为它太窄了几个像素，这说明过于精确会非常令人讨厌，而且会妨碍观察更基本的属性）。

线条和凹凸

线是一维的，而面是二维的。我们可以用光谱来定义块度，从线到面的变化意味着维度的增加。事实上，这种想法有很多可信度--分数维度是讨论分形时一个非常有用的既定概念）。用下面的图片想想一个形状有多薄或多大。



从左到右，这些形状变得越来越巨大。

哪些形状容易折叠？

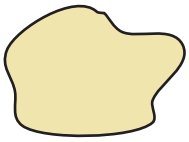
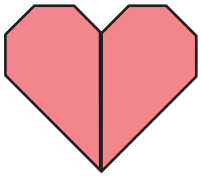
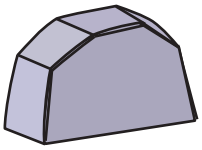
简而言之，就是质量。毕竟，我们从一个正方形开始，它就已经是一个质量块了。最简单的折纸底座通常都非常大。线条的折叠也不难--只需将纸沿同一方向对折几次，就能任意缩小。将多个质量块和线条组合在一起才是最棘手的。

抽象主题

在树形理论中，主体近似于剪影（或更多--参见第 60 页的 "设计背后 "章节中的 "Psyche"）。不过，我们并不是从一个主题开始，而是要简单地思考一下质量和线条的各种配置。我将尝试按照难度排序，这很棘手。你可能不同意我的主观排序，当然，这很正常。

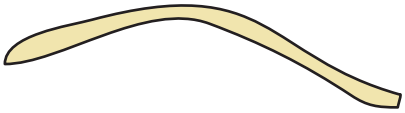
单体

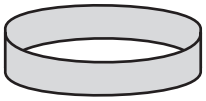
单质量模型只有一个质量，没有线条。质量块上可能会有一些凹痕（眯起眼睛就会消失）。

单线

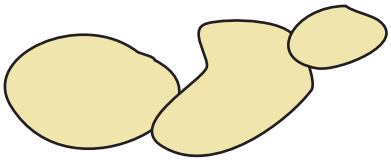
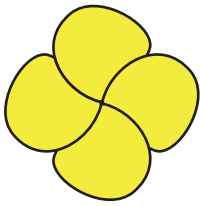
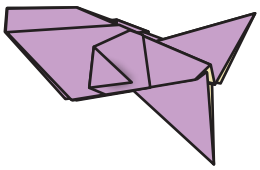
单线模型只有一条线，没有砝码，通常比单砝码模型更难弯曲。





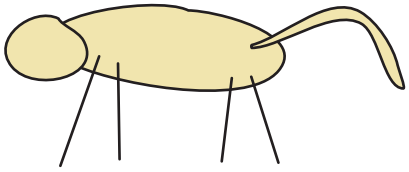
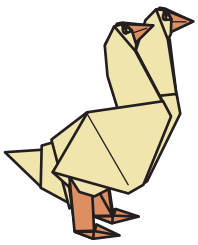
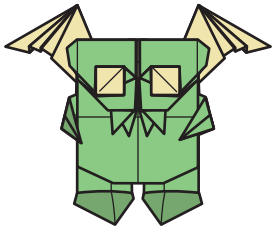
多区块

很难区分多个质量块组合在一起还是一个质量块。正如我们所提到的，这只是一个非常笼统的分类，所以不用担心确切的界限。花朵和鱼通常都属于这一类。

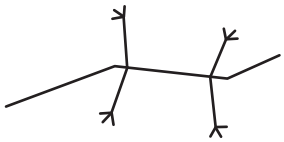
带线条的质量

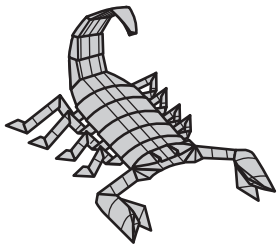
中心有一个或多个团块，团块上延伸出一条或多条线。这是哺乳动物和鸟类的典型特征。

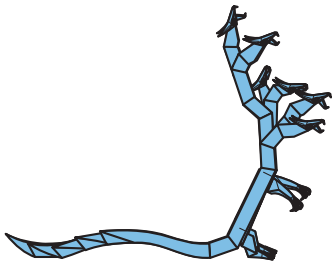




树

这些多线形态呈丝状，自然沿袭了树木理论中的棍棒图形。这些图案的特点是有许多凹槽，常见于昆虫和爬行动物。

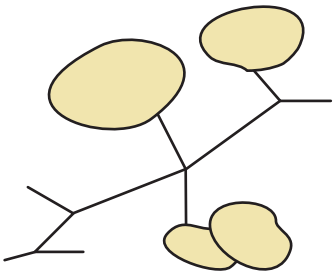


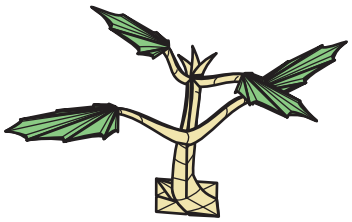


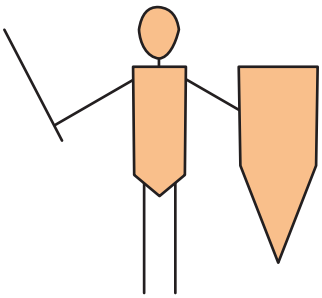


带积木的树

在自然界中，这些形状主要出现在植物中。在其他情况下，它们通常是具有多个主体的图形（例如手持盾牌的男子）。







最后一类比较棘手（从纯粹折纸的角度来看），因为各元素必须在正方形内排列。各元素之间的纸张较多，而两端的纸张较少，因此模型中间会形成团块，襟翼向两端收缩也是正常的。您可以用水槽来收缩中间的纸张，从而抵制这种趋势，上述树型中的许多模型就是这种情况。不过，尽管它们看起来薄得一致，但如果你折叠一个，就会感觉到中间还有很多层纸（有时还能看到）。

要完全打破这种自然趋势则要困难得多。这需要在两块凹凸不平的区域之间架起一座精细的桥梁，而这恰恰与纸张应有的状态相反。即使是看似简单的设计和折叠，也需要耗费大量的精力，比如四叶荨麻。这也许是植物很少被画出来的主要原因。

你可以扩展上面的线条和凹凸系统，增加一个具有更多线条和凹凸配置的类别，但这并不会使该类别在本质上变得更难，因为难度的最大障碍已经被克服了。

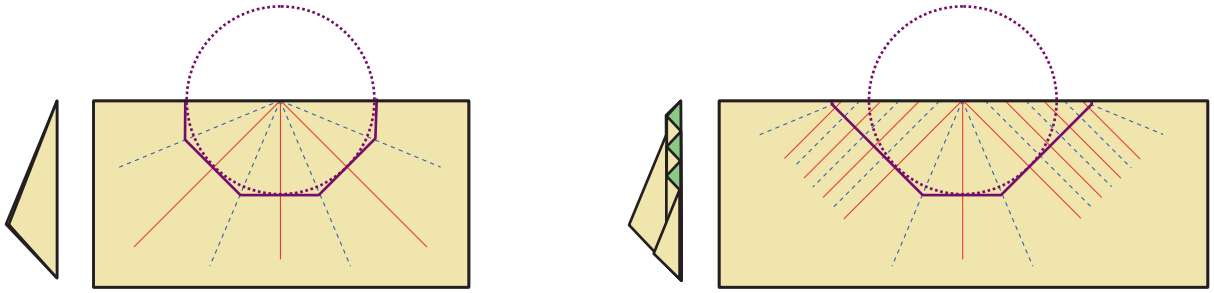
那么，我们如何看待植物呢？

我们并不一定要因为某种方法会导致模型的棘手而加以避免，但我们确实必须考虑到这种困难，以减轻任何潜在的痛苦。就荨麻而言，这意味着我们必须大大限制制作叶子的数量。

树叶

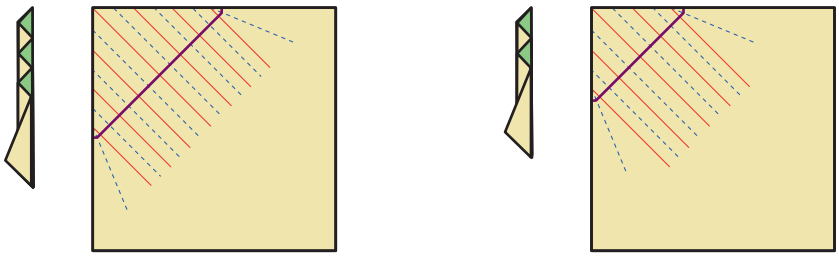
常规襟翼（叶节点）的末端一般是一个点。例如，下图左侧显示了一个 22.5° 的瓣。由于这是一个 22.5° 的襟翼，所用的纸张是八角形的。在这里，八角形垂直于它们交叉的原始边缘（沿着铰链的褶皱）。这样，相邻的襟翼就可以尽可能靠近原边。这样可以有效利用空间，但不会留下任何多余的纸张，可以铺开使襟翼更宽。

相反，我们将使用不垂直于原边的更宽的形状，如下图右侧所示。沿着原边的宽区域上下呈之字形，可以打开形成一张纸。



左：正常的 22.5° 边缘瓣。右图：一个更宽的瓣，褶皱可以展开。

我们还可以使用其他类似的形状，但这是使用 22.5° 角的最简单结构之一。这种形状的主要优点之一是，我们可以将其改装成角瓣，褶皱的外观保持不变。我们还可以通过改变褶皱的数量来改变这种形状，从而获得更大或更小的薄片。



左图：生角处的褶裥襟翼。右图：褶裥较少的小挡板。

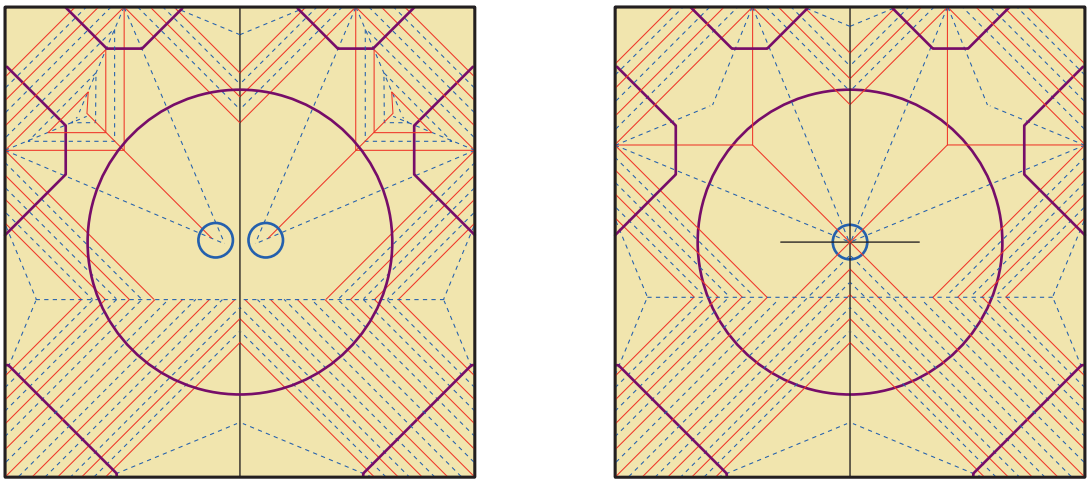
为了简化起见，我们暂且不考虑从正方形中间长出的叶子。相反，我们将把正方形中间剩余的所有纸张分配给一个茎。

安排

现在，我们需要在正方形的四周放置一些这样的叶子。一般来说，如果我们有几片大小相似的叶子，我们应该尽量在一片中心叶子周围放置六到八片边缘或角落的叶子。这样，一个茎周围就有六到八片叶子。对于一株植物来说，八片叶子是非常少的，但你必须在纸张允许的范围内加以利用。事实上，考虑到上面叶片的额外宽度，我们应该谨慎行事，因为我们可能只能放六片叶子。

叶子往往是成对出现的，所以我们要决定对称排列。植物顶部的叶子也会变小，所以我们要尽量在纸的下半部分摆放一对大叶子，上半部分摆放两对小叶子。在这种情况下，我们可以找到一种可行的排列方式，就是下面左边的这种。和往常一样，在这个阶段它并不是一个精确的 CP（纸张没有折平），但它大致显示了我们的襟翼的位置。

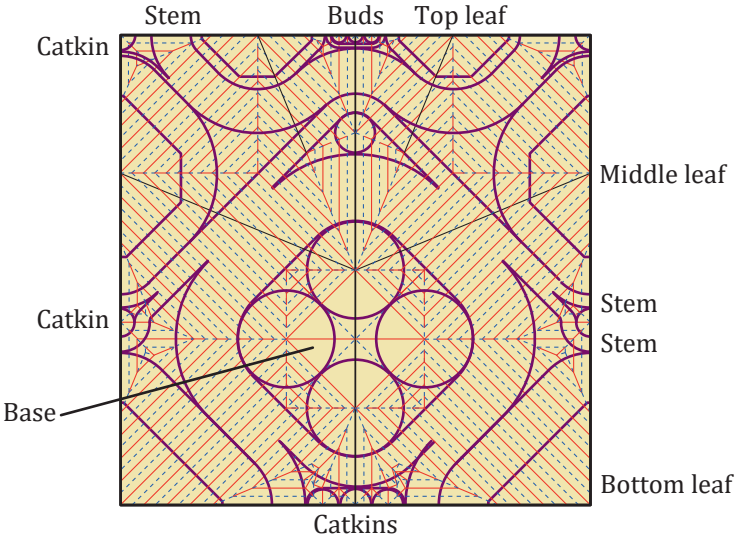
这个布局的主要问题是有几个折叠没有完全吻合。这些褶皱在左图中被圈了起来。这些褶皱都非常靠近纸张的中心。因此，我们可以解决这个问题，方法是从准确的中心点强行拉开这些褶皱，看看会发生什么。这个中心点还提供了一个很好的参考点。

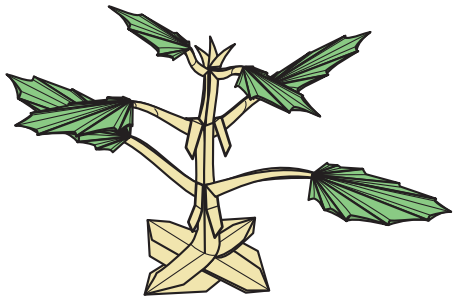


左图：初始排列。右图：褶皱在正方形中心对齐。

外围的折叠都是可行的，但如果你尝试折叠上面的图案，中间的茎部就会一团糟。其中一个问题是，茎部需要比底部的大叶子更远离顶部的小叶子，因此我们需要将茎部向下移动。如果我们能得到一个更宽的平面区域，而不是一个点，这样就能让模型直立起来（折纸植物的平衡问题是其设计的另一个难点，这里的解决方案也是在一条线的末端做一个凹凸）。

解决这种难题的最佳方法是延长现有的线条，而不是创建新的线条。如果这样做，我们就能得到一个精确的正方形区域作为模型的基础。我们甚至还可以在适当的位置用几张备用纸张作为柔荑花序（荨麻悬垂的开花部分）。通过填充河流和添加一些细节，我们就得到了下面的折叠图案--我将把制作这个图案留给新手作为练习。

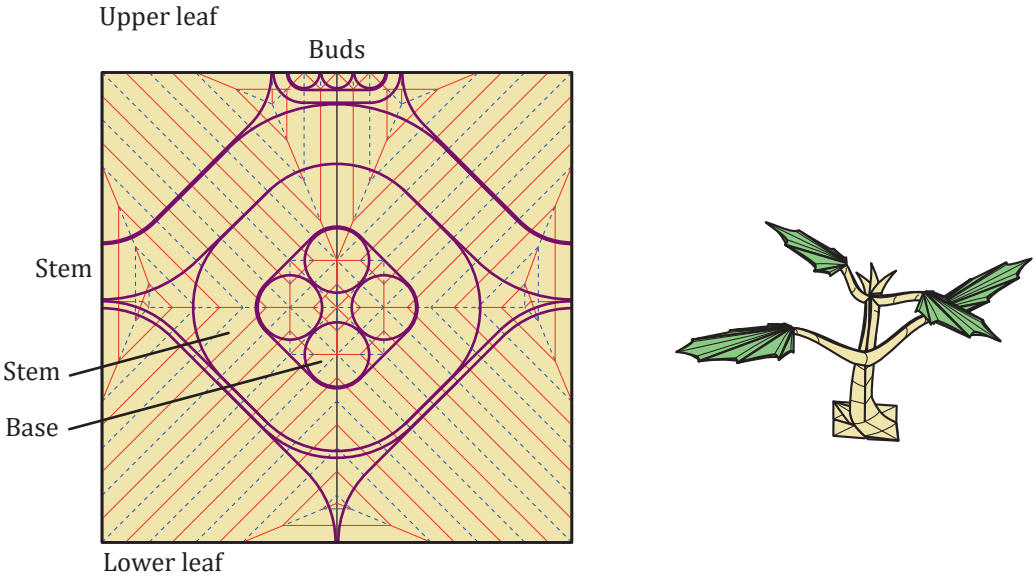




六叶荨麻 CP。

第二种安排

我们在前面提到，与其他具有类似叶片数量的物体相比，植物相对复杂。那么，这种六叶荨麻到底有多复杂呢？对我来说太复杂了。即使有容易找到的参考资料、对称性和规则的叶片图案，折叠起来也很乏味，最好还是将其作为 CP。就本图而言，我们应该选择更简单的。因此，我们要将纸张数量减少到四张。下图是最终的 CP（四张）。



四叶荨麻的 CP 和折叠模型。

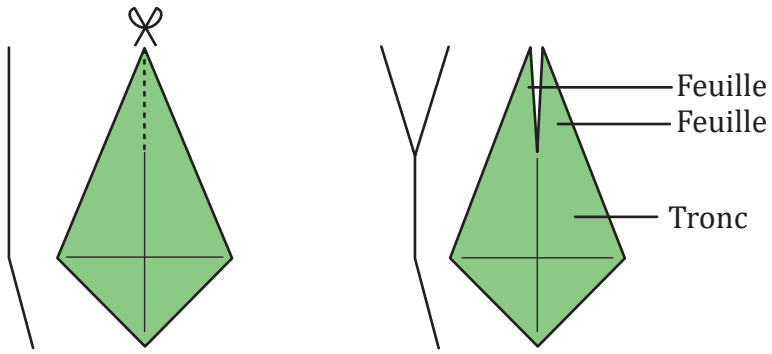
你可能会觉得我突然间就把这个排列组合扯了出来。如果你有兴趣学习如何设计折纸，你可能想知道我是如何想出这个图案的。有三个原因我就不细说了：

- 这反映了实际的 CP 经验。我在 "六叶荨麻 "上花了更多的时间，在被迫逐渐减少叶片数量后，上面的 CP 就相对明显了：就像一些传统底座一样，我们可以用四个粗糙的角来做四个长瓣。
- 我不想让人觉得这种安排客观上有什么巧妙或特别之处。有许多折叠数和襟翼长度不同的设计同样有效：您可能想探索其他的可能性。
- 从失败中学习和从成功中学习一样明智（如果不是更明智的话）。你可能会认为把六叶荨麻称为失败是夸张了，但我心中有一个特定的愿景，而且由于折纸植物比其他主题困难，我不得不大幅调整我最初的期望。这就是本章的真正教训。

最后一点是定量的：这只荨麻有四个大瓣（末端有颜色变化）、一个中瓣和一些非常小的细节，但它有 80 多个步骤。本书中瓣膜数量最相似的双头鹅只有 40 个步骤。因此，我们可以得出一个（非常）粗略的结论：折纸植物的制作难度要比具有相同襟翼排列、但质量和线条配置更简单的模型高出一倍左右。

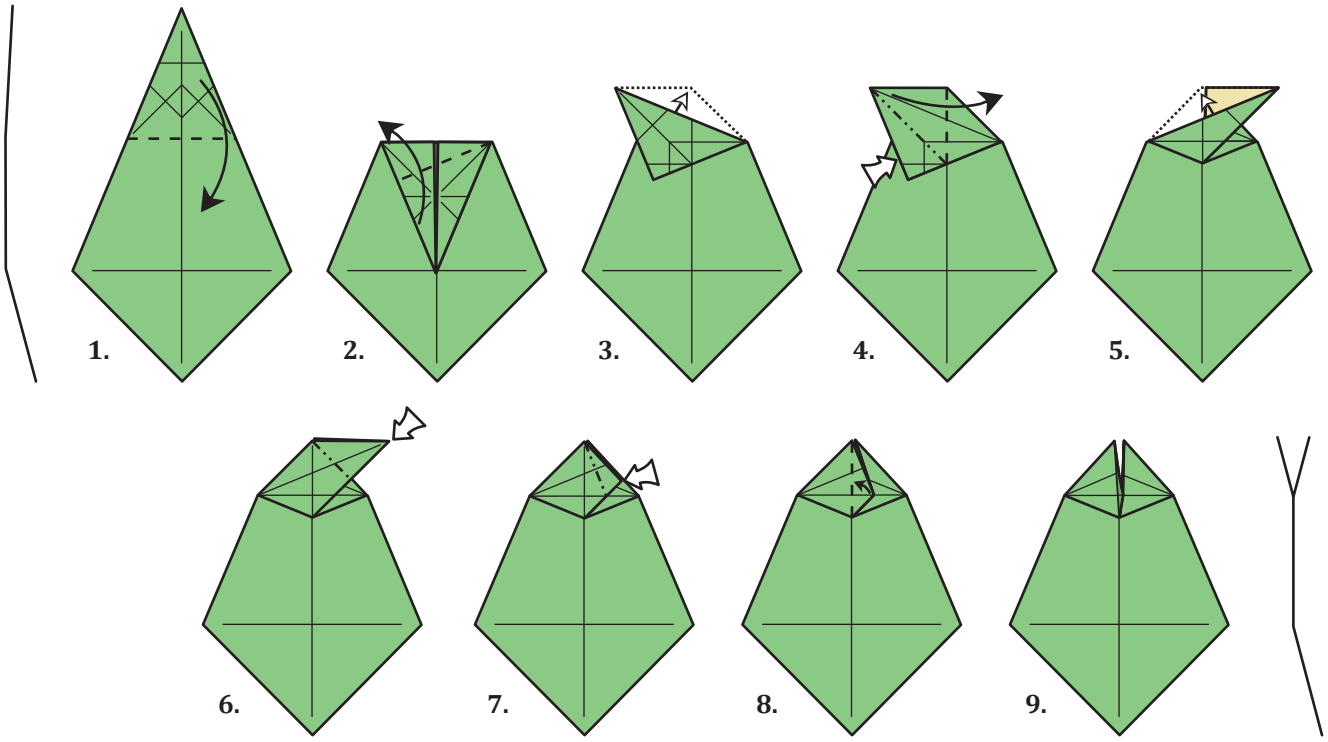
积分分配

折纸制作者的标准技巧之一是将一个瓣变成几个瓣。这就是所谓的 "分点"。历史上，这种方法是将一个襟翼从中间切开，形成两个与原襟翼长度相同的新襟翼。在尖劈法中，我们称每个新的瓣为叶片，未剪切的部分为树干。



剪出更多的挡板，剪前和剪后都有纸树。我们可以不使用剪刀来模仿吗？

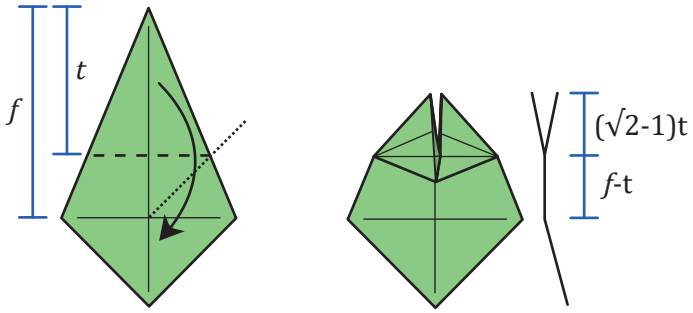
纯粹的折纸爱好者会对这种方法不以为然，他们只会对纸张保持完整的方法感到满意。也许最常用的除点方法就是下面图示的方法，我称之为 "除以 2"。这个序列的第一部分在《切肤之痛》的第 39 步至第 43 步中使用。第 18 页的《侏儒》的第 37 至 49 步也使用了类似的顺序。



将点一分为二的折叠顺序，将一个长襟翼转换成两张襟翼。请注意，这两张纸现在是两边的襟翼。

虽然两种方法都是在原纸瓣的一半处进行分纸，但折叠后的纸张要比裁剪后的短得多，其比率为 $\sqrt{2}-1 \approx 0.41$，也就是说，折叠后的纸张只比裁剪后的纸张长约 40%。要获得更长的纸张，需要在尖端分纸时使用更多的纸张。要做到这一点，可以通过降低第一折，从而减少纸干的长度，也可以通过增大整个初始翻边的尺寸。

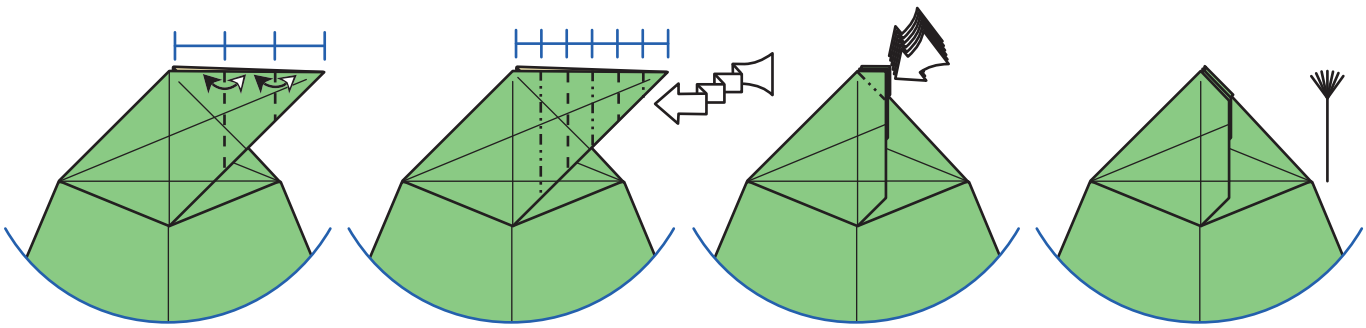
用数字表示，如果我们称初始襟翼的长度为 f，并说分离发生在距尖端的长度 t 处，那么树干的长度为 f-t，树叶的长度为 $(\sqrt{2}-1)t$。这在根据特定要求设计产品时非常有用。例如，要划分一个百叶窗，使叶子和树干的长度相同，我们需要 $f-t = (\sqrt{2}-1)t$。求解后可得出 $t/f = \sqrt{2}/2$，这样我们就可以确定初始折叠的位置（在测量或进行更多数学运算以找到精确序列后）。



稍加代数运算，就能找到获得叶子和所需长度树干的初始折叠方法。

能给我们更多提示吗？

如果我们只能得到两个叶尖，那么叶尖除法很快就会用完。我们可以通过调整除以 2 的序列，得到一种获得 n 个相等叶片的通用方法，我们称之为除以 n 方法。下面是其中一种方法的示意图。



1. 从分成 2 的前 5 步开始。然后将顶边分成 n/2 段（四舍五入）。

2. 一系列内外倒褶。

3. 一系列反向折叠。如果 n 是偶数，则将中间的角也折起来。

n 个倒置内褶的折叠。这些图使用 n = 7。

当 n 为偶数时，上述序列的效率会稍高一些。下面我让你来做个实验。

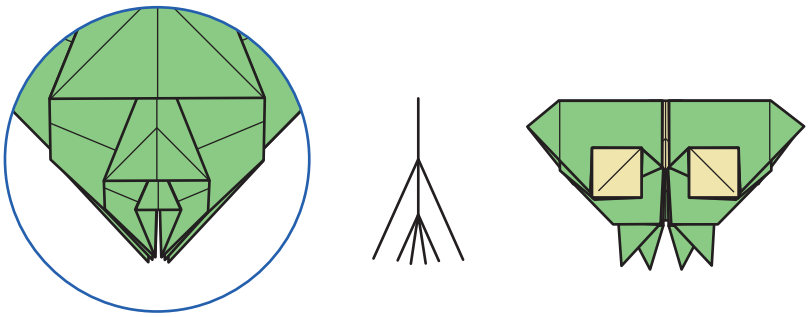
你会发现，随着 n 的增加，每片叶子的长度都会减少，从而增加树干的长度。在实际操作中，这意味着除非你只想要很小的叶尖，否则要制作大量的叶尖在物理上是很困难的，而且效率也很低。

不同长度的板材

目前所见的点划分树相对简单，但没有理由要求所有树叶都具有相同的长度。最简单的方法就是改变 n 分割线中垂直线之间的距离。

请记住，叶子越长，树干的长度就越短。因此，不同长度的树叶之间不可避免地会出现新的河流，因为这些树叶是从树上不同位置分枝的。

卡特胡》的第 39 步至第 56 步展示了如何使眼瓣比触手长。这样做效果特别好，因为树上的新河流是在眼睛和触手之间形成的，在最终模型中将这些元素分开。

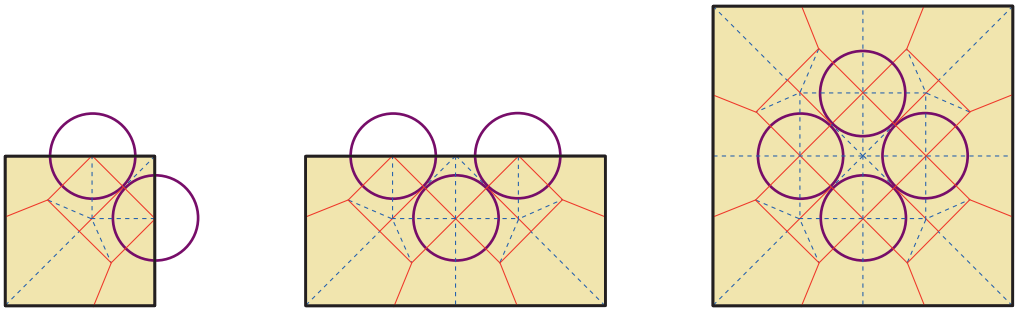


底座（第 57 阶段）、树和完成的 Cutethulhu 头像。

不是来自广场四角的百叶窗怎么办？

到目前为止，我们只研究了被点划分的角。(事实上，我们只看到了一种角，即在 22.5°几何图形中最常出现的角。顺便提一下，你可能想知道我们如何划分其他类型的粗角）。至少在我的模型中，划分角中的点是迄今为止最常见的形式。这是因为从设计的角度来看，分点的主要优点之一是我们在规划模型底座时不需要制作那么多的襟翼。有了更少的襟翼，我们就更有可能从一个角上制作出一个大的襟翼，因此我们往往不需要使用其他类型的槽。

不过，当我们需要从边缘或中间分割襟翼时，只需复制分割的 CP，就能制作出等同于对半分割的襟翼，如下图所示。不过，与从四角形成的襟翼相比，它们的折叠难度要大得多，因为边缘和中间的襟翼有更多的纸层（见第 75 和 76 页的牛头人步骤 25 至 40）。您也可以尝试使用相同的技巧在边缘或中间的襟翼上折叠成 n 个重复的分格，这是一个很好（也很难）的练习。



左：角上的 CP，有 2 个分割点。中：垂直对称的二分法在一条边上形成一个 CP。右图：4 个二分之一分割的复制品为一个中央挡板的分割创造了一个 CP（请注意，为了让二分之一分割的重复更清晰，我完全重复了折叠，但这意味着中间和右边的 CP 无法折平--如果你想制作它们，需要稍微调整一下折叠）。

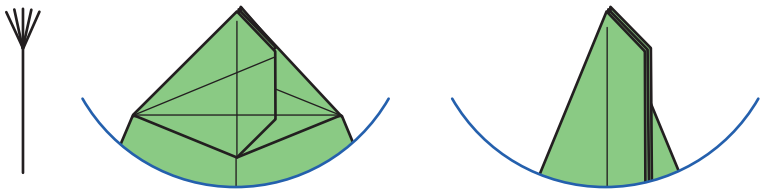
为什么要进行顶端分割--嫁接不是更好吗？

嫁接是指折叠一个已有的模型，但只使用纸张的一部分，这样就会剩下一些纸张，例如一角的纸张。这些剩余的纸张可以用来在原模型上添加额外的细节。(如果您不熟悉这个概念，可以查看第 89 页上的一个例子，或者在《折叠幻想：第一卷》中找到更多关于嫁接的讨论和例子）。您可能会发现嫁接和拆线有一些相似之处：两者都是现代设计技巧，都可以用来创造更多的点。乍一看，嫁接似乎更胜一筹：您可以在任何地方进行嫁接（而不仅仅是在长襟翼上），通过插入所需的纸量，新襟翼可以任意变长。不过，与嫁接法相比，分割纸尖有一些关键优势：

• 易于弯曲：设计师很容易低估甚至忽略这一点（我就知道！）。点分割在使用 22.5° 几何形状的模型中尤为常见，这意味着它们可以很容易地应用到现有的传统底座上。对于一个经验不足的折纸者来说，从折叠传统鸟基开始，然后分离其中一个瓣，要比从一个不熟悉的嫁接纸开始舒服得多，尽管嫁接纸随后会被折叠成鸟基。另外，在嫁接时，折叠几个不同长度的瓣也比较困难，而我们已经看到，用点分割的方法就很简单。

• 实用配置：点分割减少了在进行圆环包装设计时需要寻找的选项数量，因为我们可以将襟翼的不同子集组合在一起，以创建更简单的树（见第 47 页）。无论如何分组，即使子面板保持在大致相同的位置，也能更容易地找到合适的圆排列方式，就像《Cutethulhu》中鱼的底座一样。虽然在找到基底后再进行嫁接也能简化最初的树形，但必须考虑到沿途多出的纸张，而且要有效利用这些纸张还需要做更多的工作。

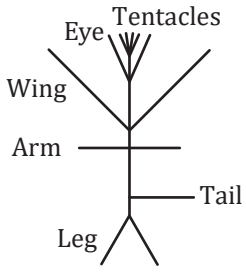
• 更宽的瓣面：与嫁接相比，分割梢头自然会留下相对较宽的瓣面。当然，这是否是件好事取决于主题。



左：一棵树。中间：准时分离 45°瓣，形成树。右图：在 45°瓣中间嫁接，形成树形。将顶端分开可形成更宽的瓣。

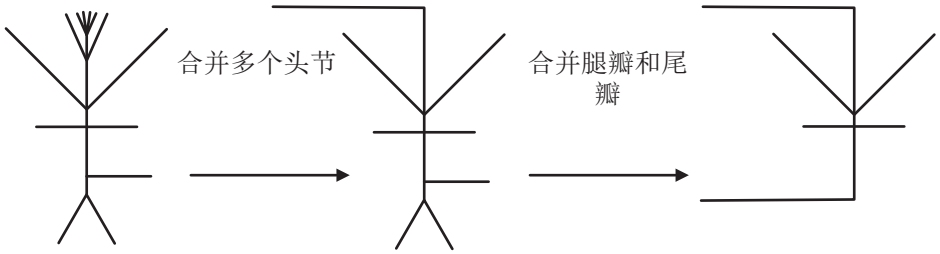
• 组件独立性：点拆分的一大优势在于，它允许设计者分阶段而不是一次性地创建模型，从而在标准设计流程中引入了额外的步骤。最简单的示范就是举例说明，让我们继续分析 Cutethulhu。我们已经了解了如何使用点分割来制作头部，下面让我们回过头来看看这个模型的整个设计过程。

1. 评估研究对象并建树。



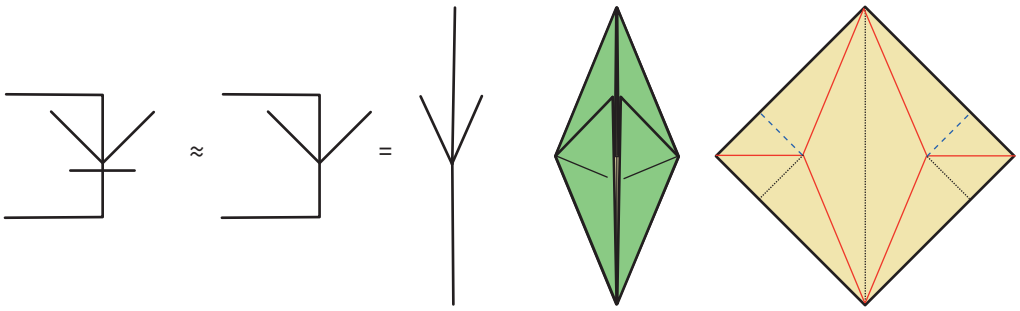
这是卡特胡树的粗略草图。(头部的襟翼是上下颠倒的，因为这意味着小襟翼都可以从原边开始制作。这意味着我们必须在折叠过程中将头部向下折叠，但这不是问题）。

2. 将一些小板块合并成一个大板块，从而简化树形。



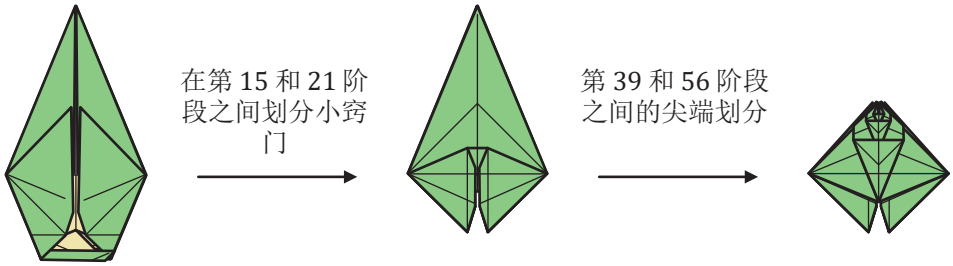
头部襟翼的组合促使我们也考虑将腿部和尾部组合成一个襟翼。这样，树的上半部和下半部就会对称，从而更容易制作底座。

3. 创建或确定与简化树相对应的基数。

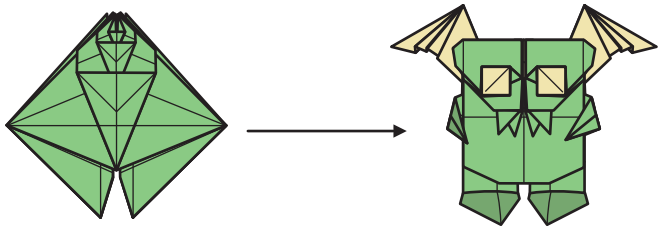


如果我们忽略较小的襟翼，鱼的传统底座就是树。我们稍后再处理这些较小的襟翼，但现在还是继续吧。

4. 将大襟翼分成若干点，以重现步骤 2 中移除的小襟翼。



5. 完成模型折叠。



鱼底部的钝角可以变成小臂，这样我们就拥有了折叠最终模型所需的所有襟翼。

6. 如果我们决定使用垂直嫁接来添加头部和腿部的襟翼，那么就不存在与第 4 步中的独立点划分相当的问题。这是因为嫁接是在整个正方形上进行的，所以如果两端都有合适的嫁接，我们就必须同时考虑到上下襟翼所需的纸张。但是，通过分割顶端，我们可以将头部和腿部分开折叠。事实上，我们甚至可以在这一阶段调整头部的高度：步骤 38 中的水平谷折只是为了方便，但如果折线更靠近纸张顶部，则可以制作出更高的模型。我建议您试一试！

PSYCHE

在希腊神话中，普赛克是美丽的灵魂女神，经常被描绘成拥有蝴蝶翅膀的形象。

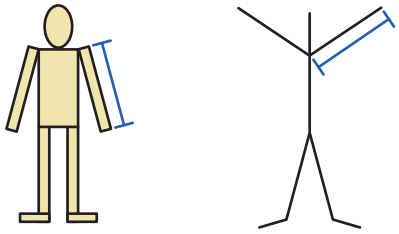
如果使用金属化纸，您会更容易制作出这个模型，因为金属化纸可以制作出手臂、脖子和头发等细节。

对于好奇者，第 60 页解释了左侧不寻常的 CP。

树木理论

许多折纸设计师都使用树形理论来制作自己的模型。如果你从未听说过树理论，我建议你阅读一本更全面的相关书籍，以便从这部分内容中获得最大的收获，但我会在下文中给你一个简要的总结作为提醒。

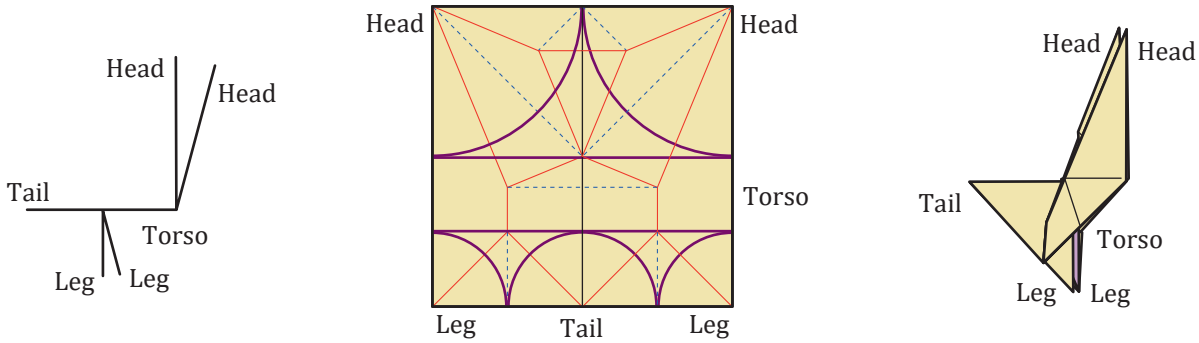
创建模型时，我们的目标是为主题的每个特征折叠一个窗格，为此，我们需要知道每个窗格的大小和位置。树状理论将主体信息压缩成一个棒状图，称为树状图，从而简化了设计过程。每棵树都由边（线）和顶点（每条边两端的点）组成。这就将每个特征的维数减少到了一条线。树中每条边的长度必须与特征的长度相同（相对于其他特征而言）。



树中一条边的长度在主题中是相同的。

接下来，我们需要计算树的每条边在正方形上要用多少纸。只在一端与树相连的边（如手臂）称为叶边，未相连的顶点称为叶顶点。叶缘可以在纸上用一个圆来表示（通常我们只显示圆与正方形相交的部分）：圆心是折叠模型中挡板的一端，圆的半径是挡板的长度。另一方面，两端相连的边缘（例如躯干）是分支边缘，可以用一条宽度不变的纸条表示，称为河流。河流的宽度就是树中边缘的长度，河流的两岸就是树中边缘的两端。

如果我们将这些圆形和河流紧凑地排列在正方形内，使圆形和河流按照它们在树中的相邻关系接触（但不重叠），我们就得到了一个圆形和河流的排列。这个排列可以折叠成一个带有所有所需翻边的底座。如果折叠后的模型相对于起始正方形较大，并且最有效的排列是最优的，那么这种排列就是有效的。



左：双头鹅树。
中间：双头鹅的 CP，显示圆圈和河流。右图：双头鹅的折叠底座。

树理论问题

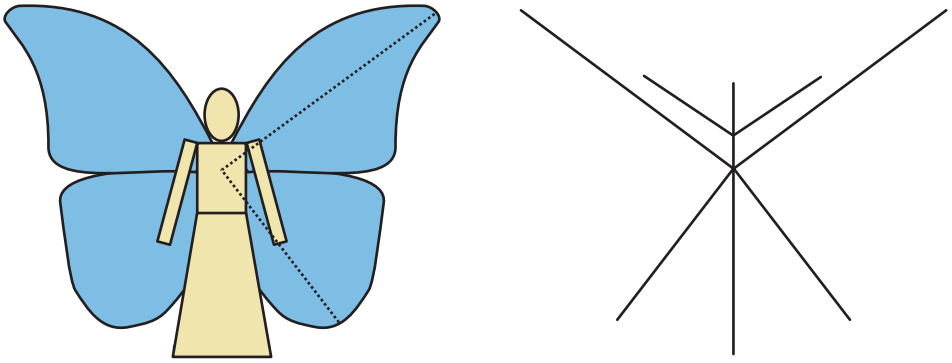
树木理论无法做到某些事情，但在我看来，最大的问题是我们无法控制襟翼的宽度。高效的排列方式往往会产生较薄的百叶窗。这是因为挡板的宽度只是由于挡板之间空间中多余的纸张造成的。对于身材高大的拍摄对象来说，这种高效率的结果可能是件好事，但对于五官宽大的拍摄对象来说，对襟翼宽度的追求实际上违背了高效率的原则。

这并不奇怪，因为树的制作方法是：当我们把每个元素变成边缘时，我们会去掉整个襟翼的宽度。因此，整个圆的排列过程只能确保树的形成，而不能确保主题本身。设计者通常会采用这种近似方法，因为纸张不可能像线条一样厚度为零；襟翼总会有一些宽度，而且大多数情况下，这些剩余的纸张量就足够了。例如，用上一页中的圆圈/河流布置制作的双头鹅，其折叠的底座就很方便地构成了鹅身的形状，而无需额外的工作。

大多数情况下，当一棵树与主题的近似程度很低时，树的理论并不能让我们有条不紊地解决这个问题。因此，在本节中，我将以我的模型 "Psyche "为例，解释一种新方法（据我所知），这种方法可以扩展树理论，以考虑襟翼的宽度。

树冠理论

与往常一样，最简单的方法是从这个例子开始：一个长着蝴蝶翅膀的人物。当您尝试为这个主题绘制一棵树时，您会立即遇到一个难题：蝴蝶共有四只翅膀（两只前翅和两只后翅），但您是应该将前翅和后翅的两侧连接起来形成一个大的瓣，还是将它们分开呢？在这两种情况下，树上相应边缘的长度应该是多少？当我们尝试制作一棵树时，结果与想要的主题几乎没有相似之处，因此我们开始怀疑这些问题是否正确。



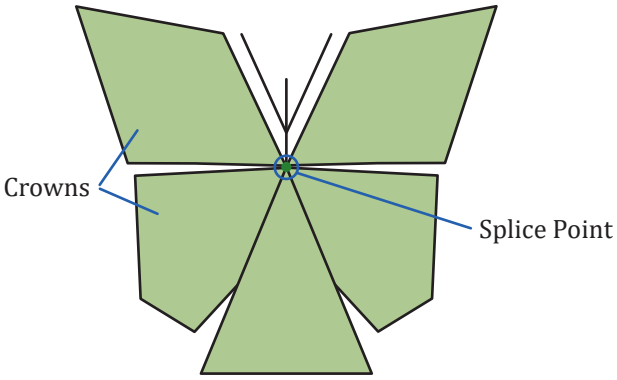
左：我们的研究对象--赛琪。右图：一棵树，其翅膀的长度相当于铰链与每只翅膀尖端之间的距离。这是对 Psyche 的近似：通常情况下，我们会从树上认出被摄体，但这棵树让我们想到的更多是怪物，而不是美丽的女神。

问题在于如何逼近一维线条，因此自然而然要考虑用二维形状来逼近特征。折纸的折线都是直线段（如果你想纯粹地参考每个折痕的话），因此曲线可能不是一个好主意；我们应该使用多边形。我们还需要确保每个多边形都是凸形--所有角度的最大值都是 180°--因为不可能从纸的连续区域折出一个大于 180°的角度。

我们没有必要把事情复杂化：如果线是一个特征的合适近似值，那么我们就应该使用边，就像每个成员一样。任何新添加的内容都必须与现有理论兼容，这样我们才能使用现有的方法。

改良树木

我们将使用一个稍微复杂一点的数学对象：树图，但带有一些多边形区域，而不是用棍图来近似。我们需要给这个对象起个名字，最好继续使用基于植物的命名法。因此，我将这种更通用的结构称为植物图（或简称植物）。与荒芜的树木不同，这些物体有大片让人联想到叶子的区域--我把这些区域都称为树冠，并将它们染成绿色。每个树冠都连接到植物图的拼接点上，将树冠添加到现有树木/植物图的过程称为拼接。

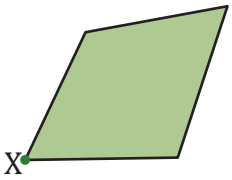


赛琪的植物图，五个树冠分别代表两个前翼、两个后翼和裙子。目前，这些形状只是我们在探索植物图解的可能性时的示例，如有必要，我们可能会在以后对它们进行调整。

树木很容易绘制，因为边缘总是可以移动，不会与其他边缘交叉，而植物图中的树冠却不一定在页面上的正确位置而不会重叠。在绘制 "赛琪 "的植物图时，我们需要注意在后翅和裙子之间有一个三维空间。关于三维空间，我想补充的是，最终模型的任何曲线部分都需要比二维投影图更多的纸张。例如，裙子最好做成圆锥体或圆柱体，因此我们可能希望稍后加宽裙子的冠部。

皇冠

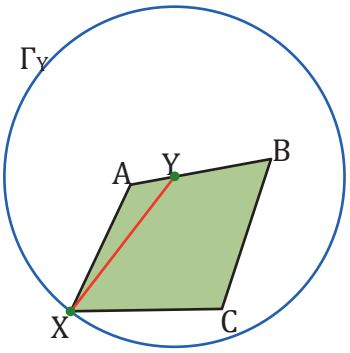
让我们来考虑一下单个冠所需的纸张；我将以右上前翅为例。要回答的最重要的问题是：这个冠在正方形上需要占用多少纸张？为了便于参考，我们可以假设树冠将是一个连续的纸张区域（因为如果由于某种原因不希望这样，我们总是可以将纸张分成几个凸次多边形来代替它们--见第 68 页）。



右上前翼的冠。冠的接合点位于 X 处。

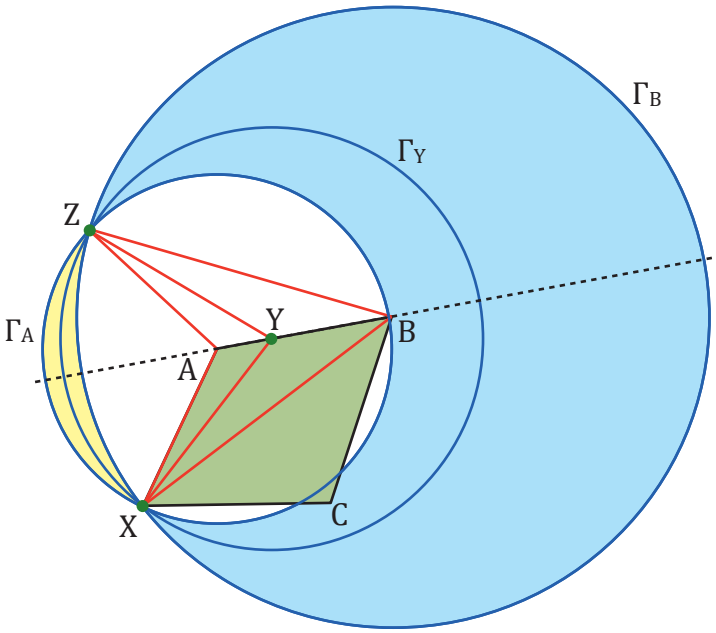
到目前为止还算容易，但冠外的纸张怎么办？靠近前翅叶冠边缘的纸张可能必须在前翅叶瓣中，但有多远？在树的理论中，我们会在叶子的顶端画圆，因为圆是距离襟翼末端一定距离（襟翼的长度）内所有点的位置。在这里，我们将使用相同的思路，但不是只看叶片的末端，而是沿树冠边缘看所有的点。

例如，沿线段 AB 看任意一点 Y。线段 XY 显示为红色。任何不在前翼上的纸张都必须距离 Y 至少 XY，因为它只能通过 X 处的拼接点与 Y 相连。这就在 Y 周围形成了一个圆，即 ΓY（"伽马 Y"）。换句话说，在这个蓝色圆圈内的任何一点都离 Y 太近，无法成为任何其他元素的一部分。



前翅的冠部，以 Y 为圆心，半径等于 XY 的距离。

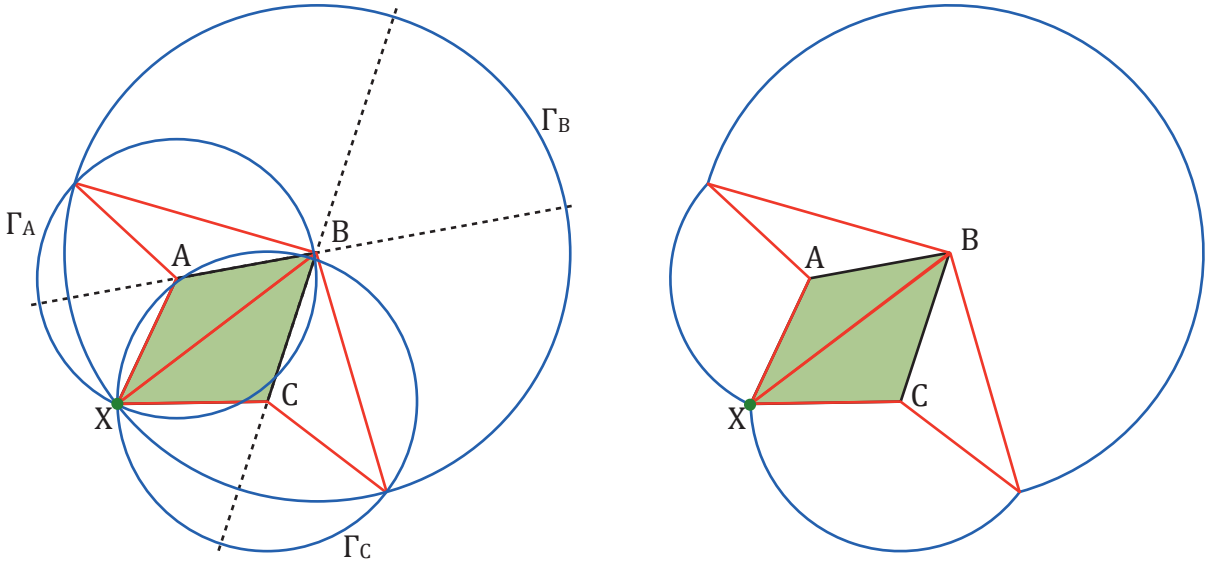
同样的论证不仅适用于 Y 点，也适用于皇冠上的任何一点。特别是，还要考虑以顶点 A 和 B 为圆心的圆，我们分别称它们为 ΓA 和 ΓB。这不是巧合：所有这些圆都围绕直线 AB 对称，因此 Z 是 X 在直线 AB 上的反射。



所有以 AB 为圆心、经过交点 X 的圆也经过 Z。以 Y 为圆心的圆完全包含在两个阴影 "月亮 "中。

ΓY 的小（较小）弧 XZ 夹在ΓA 和ΓB 的小弧之间：这一区域被称为月亮，上面的阴影为黄色。同样，ΓY 的主弧 XZ 也位于ΓA 和ΓB 主弧之间的淡蓝色月亮中。这两个事实结合在一起，意味着以 Y 为圆心的整个圆都包含在圆ΓA 和圆ΓB 的结合处。由于 Y 是任意选择的，因此我们只需考虑圆 ΓA 和 ΓB，而无需查看 AB 上的每个点。这个论证不仅适用于　AB，也适用于皇冠的其他各条边；我们只需考虑以皇冠顶点为圆心的圆即可。

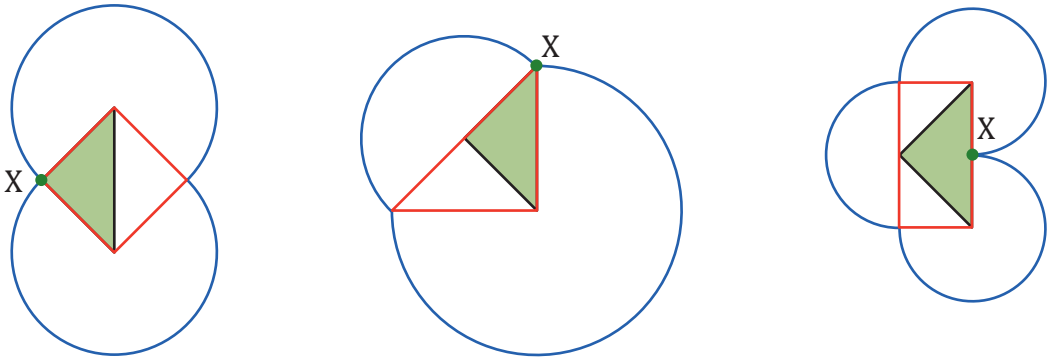
我们只需考虑以皇冠顶点为圆心的圆。我将把通过这一过程得到的圆的结合称为皇冠的冠层。如果我们对前翼使用原来的棒形近似图，则只需使用圆 ΓB。从 ΓB 到整个机冠，所需的额外纸张实在太少了。



ΓA、ΓB 和ΓC 的结合构成了皇冠的顶盖。

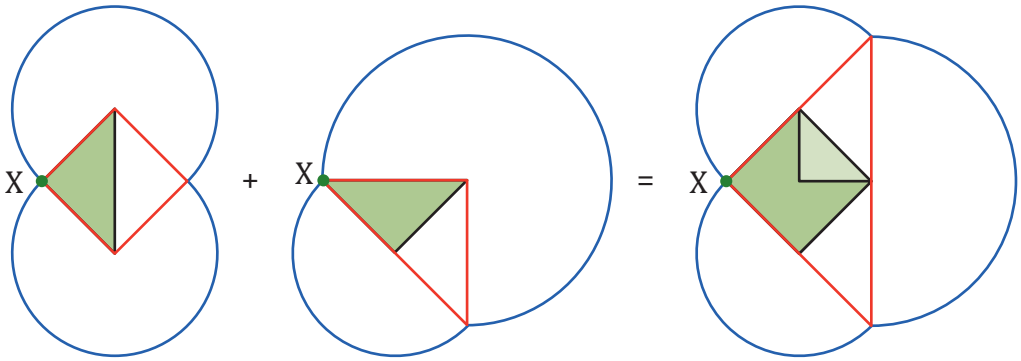
其他类型的牙冠

让我们通过观察其他简单的树冠形状来探索树冠的一般特性。



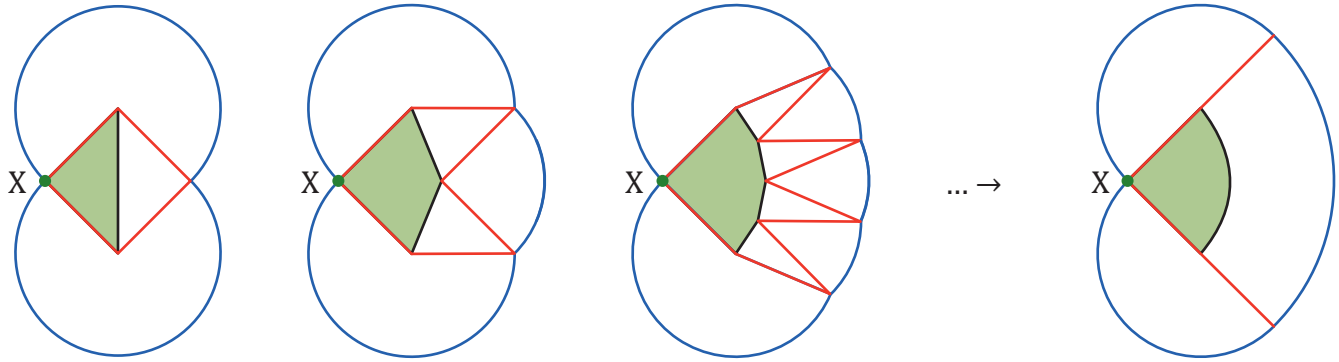
45-90-45 三角形的树冠形状。请注意，树冠的形状取决于交界点的位置，交界点不一定是树冠顶点。

如果我们将任意两个树冠在交界处叠加，就会得到一个新的树冠，它是两个独立树冠的结合。但是，新树冠可能不是凸形的。在这种情况下，新树冠是包含两个原始树冠的最小凸多边形--这种形状称为凸封闭。我们可以从上面前两个树冠的例子中看到这一点。



添加具有相同交点的遮阳篷：取皇冠的凸封闭和遮阳篷的联合。这是一个交换操作（顺序并不重要），因此可以添加有限数量的遮阳篷。

我们还可以通过树冠的边界来得到一个树冠不是多边形的结合体。例如，在下面的树冠序列中，每个树冠的顶点都依次增多，且与交点的距离都相同。这个过程的边界是一个圆弧。这一点非常有用，因为计算圆的距离比计算多边形的距离更容易，所以在寻找排列组合时，这个过程可以简化计算（无论是手动还是计算机）。



无数个具有相同接合点的树冠结合在一起，就会产生一个具有弯曲边缘的树冠。请注意，树冠右侧的区域看起来非常像一条河流。

拼接

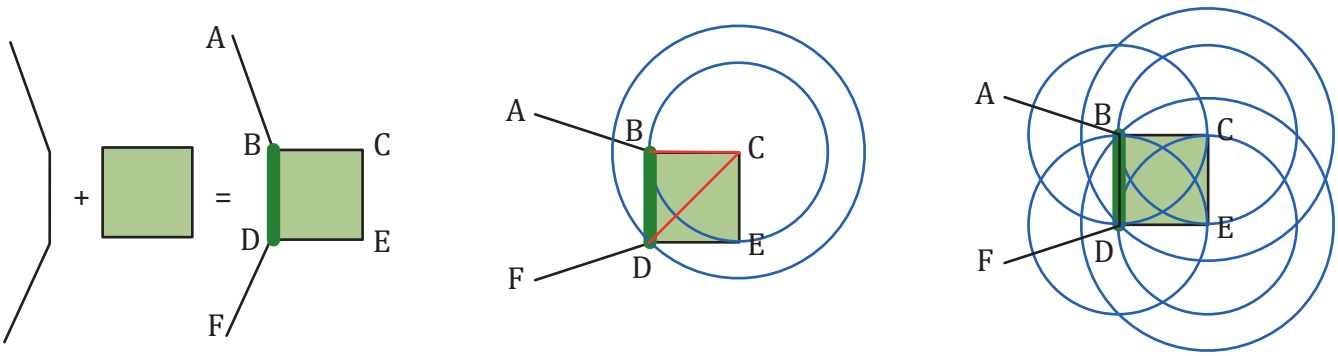
在树木理论中，边缘必须在点上相交，因为这是线条之间唯一的交点类型。但在植物图谱中，树冠可以沿着整条线（如果要精确的话，也可以是线段）与另一个元素相交。我们称这条直线为树冠的交线。有两种不同的情况需要考虑：树冠与树的边缘相交，或者树冠与另一个树冠相交。

树冠/边缘交界线

这种连接线与分支边缘有一个共同的特性：它们将植物图上的点分为两类，具体取决于这些点位于连接线的哪一边。

下面的示例是由一棵简单的树与正方形树冠沿着正方形一边的边缘连接而成的植物图。和以前一样，我们以树冠的顶点为中心画圆，但现在我们必须为每个顶点画几个圆；一个圆将穿过连接线的一端，另一个圆将穿过连接线的另一端。

例如，在下面的中心图像中，有两个以 C 为中心的圆，其中一个穿过 B，另一个穿过 D。每个顶点都需要画两个这样的圆（包括 B 和 D，但由于这两个圆是连接线的两端，其较小的圆的半径为 0，因此我们可以省略它们）。

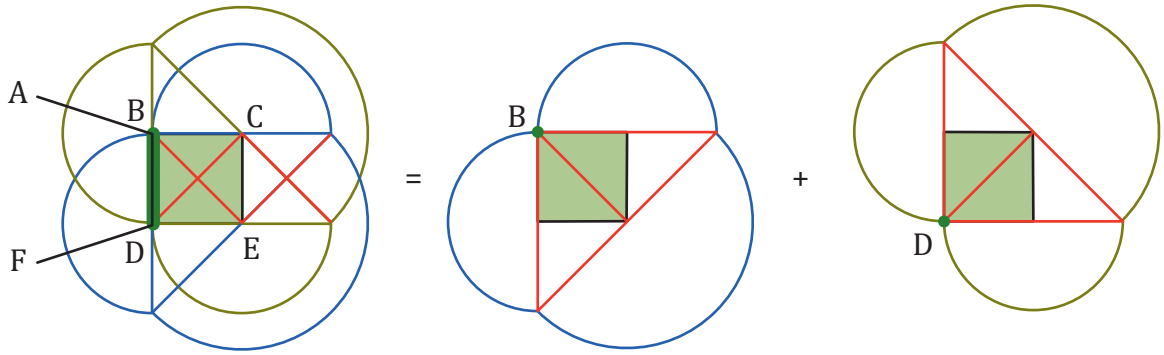


左图：通过拼接形成的植物示意图。中心：围绕 C 画出的圆圈。

诚然，这有点乱。但是，如果我们根据圆圈穿过分界线的哪一端对它们进行分类，我们就可以开始明白发生了什么--这些圆圈在下面用不同的颜色表示。

从图幅 A 的顶点来看，分界线的相关端点在 B 处。另一方面，从顶点 F 的角度来看，交界线的相关端点在 D 处。

这样，我们就有了两个叠加在一起的檐篷--它们是上一页正方形中的檐篷叠加在一起的。但这次我们有两个不同的交点。

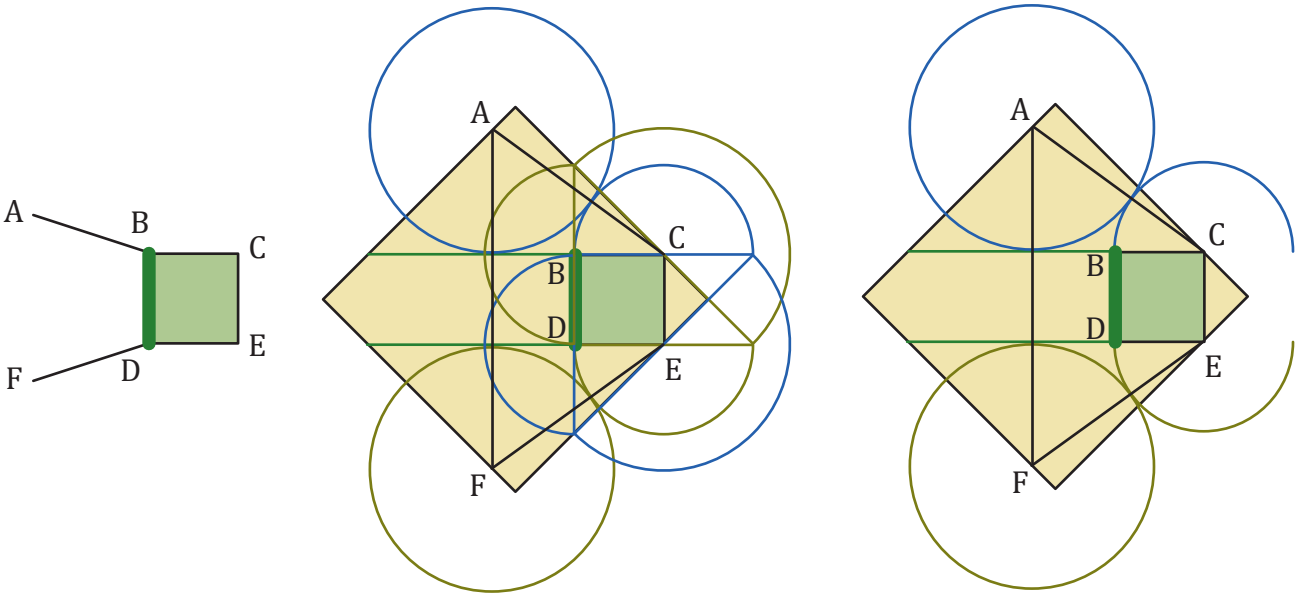


这个带有 BD 拼接线的方形树冠的树冠是由分别带有 B 和 D 拼接点的树冠组合而成的。

让我们试着把这个天篷做成某种圆形/河流/天篷的排列。当然，我们还需要为 A 和 F 画圆，像往常一样，这些圆的圆心需要在画纸上。这些圆的颜色取决于哪一端最靠近连接线，因此我们可以用一条简单的规则将这些元素分开：相同颜色的圆不能重叠。

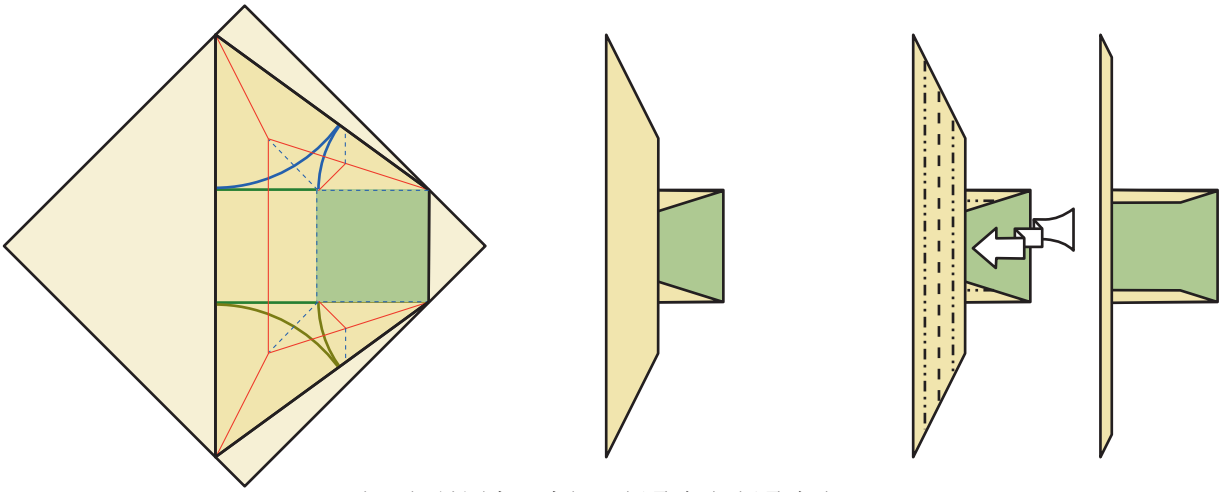
至于树冠，我们需要确保整个树冠都在画纸上。此外，分界线 BD 是分隔 A 和 F 的一条河流，因此我们在排列时不能忘记它。

很明显，A 和 F 需要相互远离，而实现这一点的最佳方法就是将它们放在相对的生角上。但实际上，如果 A 和 F 不完全在原角上，我们可以找到更有效的排列。只要稍加推敲，你就会相信下面的安排是我们能做到的最好的安排。



左图：工厂示意图。中间： 该植物图中的树冠排列。右图：同样的树冠，但为了清晰起见，去掉了一些弧线和线条。

我们迄今为止所做的一切都是理论上的，但它真的有效吗？最简单的测试就是尝试折叠。你会发现它是可行的，也许比你想象的要简单得多。下面是这种排列方式的折叠模板。



左：褶皱图案。中间：折叠底座 折叠底座。
右图：凹陷处使我们任意接近所需的形状。

或者至少可以说是可行的。在平面模型中，我们遇到了与树理论完全相同的问题（在平面模型中，两个瓣由一条轴线分隔）：要获得植物图上的理论长度，我们必须无限次地打开和闭合中央边缘。这并不现实，而且与树形理论一样，我们发现只要凹槽的数量足够多（有限），就能任意接近所需的形状。

事实上，植物图是可折叠的并不奇怪：从另一个角度看，这种排列是一棵基本的树，中间有一个嫁接条--只要中央挡板两边的纸是对称的，嫁接条就能增加所需的宽度。这是因为方形树冠的两侧是平行的，但一般情况下并非如此。

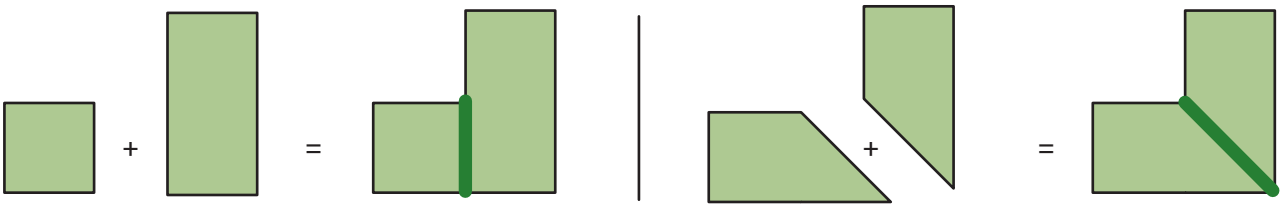
因此，也许我们很幸运--无论如何，你都无法通过实例来证明这一点。事实上，我们迄今为止所做的一切都无法验证给定的排列方式是否可折叠，更不用说创建一种算法来生成折叠模式了（这两项任务都远远超出了本书的范围）。我们从天篷理论中得到的只是一个最基本的条件：我们至少需要天篷的纸张表面才能折叠出一个连续的多边形，但我们可能需要更多的纸张。

那么，这种不完整的分析有什么意义呢？打个比方，我们来看看用树（没有树冠）画圆的方法找到的排列方式。从文件的角度来看，树理论中的精确最优排列很少是最佳排列（原因包括缺乏参考、角度不寻常、未考虑颜色变化等）。因此，我们可以移动这些点，以获得更好的参照和更容易的折叠序列。同样，树冠理论显示了大树冠的合适位置，但无论如何，设计者都必须设计出更简洁的排列方式和令人愉悦的折叠顺序，以完善设计。从实用的角度来看，进一步的分析并不能帮助我们创造出更漂亮的模型（当然，发展折纸理论还有其他原因，所以如果你热衷于研究天篷理论，请随意）。

树冠/树冠连接线

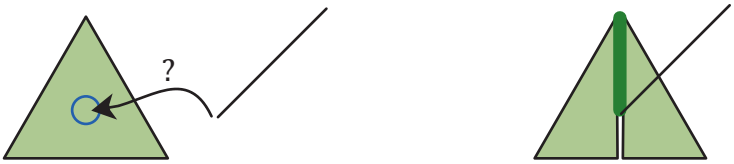
我们已经处理了简单的情况，即连接线是树木的边缘。但还有一种根本不同的情况：我们希望沿着一条线连接两个不同的树冠。

这样做的原因之一是为了得到凹多边形，即至少有一个角大于 180°的多边形。凹多边形可以通过不同的方式由较小的多边形组合而成，具有极大的灵活性。



从多个凸多边形创建一个凹多边形的无限可能性中选出两个例子。

我们可能还想分割一个凸多边形，以便在植物图中添加一条从树冠中间出现的边或树冠。例如，我们可以在等边三角形的中心添加一条边。



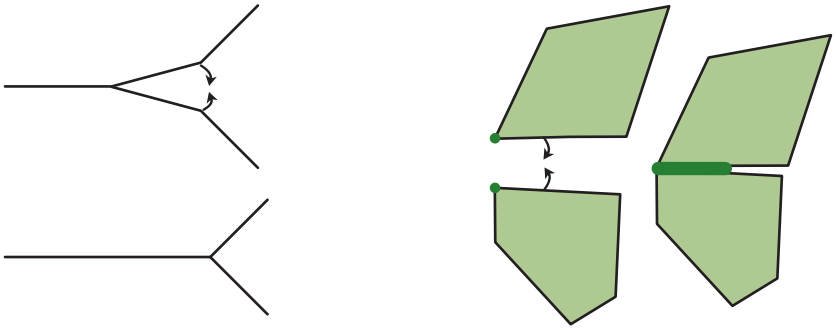
左： 如何在皇冠的中心添加一条新边？右： 将皇冠分成两个区域，然后将它们连接起来。

这种方法可能不可取，因为无法将底片重新粘在一起。另一种方法是如下图所示，通过折叠一个较大的皇冠，使边缘回到中心。在所有情况下，我们都需要决定新的边缘应该来自多边形的正面还是背面。- 这是一种在树木理论中没有出现过的考虑因素。

皇冠折叠是在区域中心增加边缘的另一种选择。

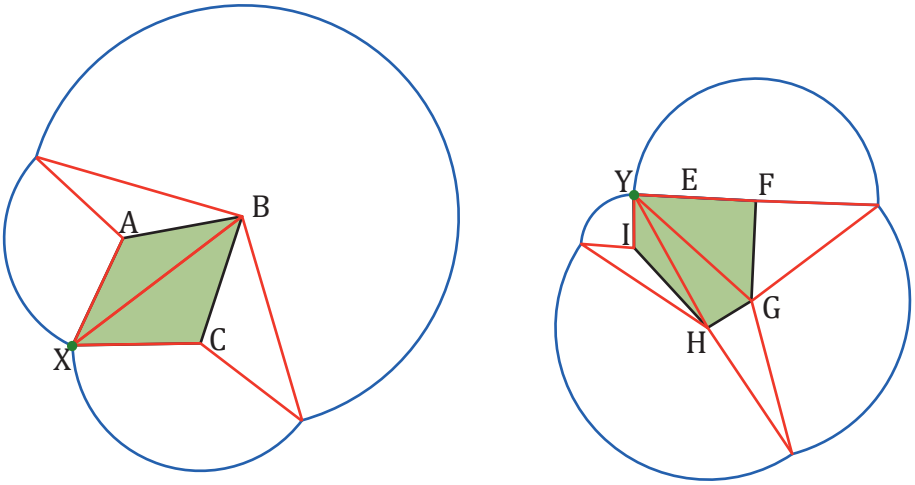
子频道

我们可以使用冠/冠连接线来回答几页前提出的问题，即我们是否应该为前翅和后翅分别制作襟翼。我们可以在两个树冠之间添加一条连接线，这是个好主意，因为将树冠连接在一起应该比单独制作每个树冠使用更少的纸张。这是在解剖精确度和效率之间的折衷方案，我们可以控制连接线的确切长度，让折纸的这些优点中对我们更重要的那一个得到更多的重视。



左图：将两条不同的边缘合并成一条河流，可以减少树木所需的纸张表面积。

画在纸上是什么样子？让我们先画出两个树冠的树冠，每个树冠都有一个交界点。

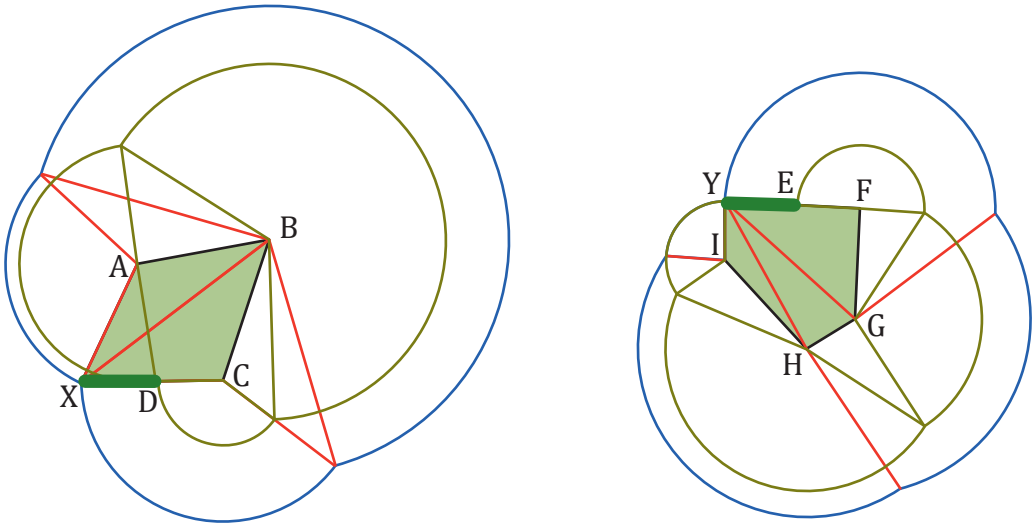


左：前翅冠层。右图：后翅冠层。

如果它们是完全独立的襟翼，我们根本无法将它们重叠在一起，但由于我们希望它们共用一条连接线，所以我们可以将它们靠得更近。让我们来计算一下它们到底可以靠得多近。

我们将在每个蝶冠上添加一条分界线--这就是下图中的 XD 线和 YE 线。考虑一下前翅冠上的 C 点。该点距离后翅上的 F 点有多远？最短的路径是通过 D（因为它是 XD 交界线上离 C 最近的点）。因此，以 C 为圆心画一个经过 D 而不是 X 的较小的圆是合理的。对于 A 和 B，我们也可以这样做，如果 XD 上的某一点比 X 更近（A 和 B 也是如此），就画一个更小的圆。这三个圆的结合处就是一个子树冠，它完全包含在整个树冠中。

同样，我们可以为后翅绘制一个子树冠；对于 F、G、H 和 I 中的每一个，如果到 E 的距离比到 Y 的距离短，我们就绘制一个经过 E 的圆。这些圆构成了后翼的子副本。



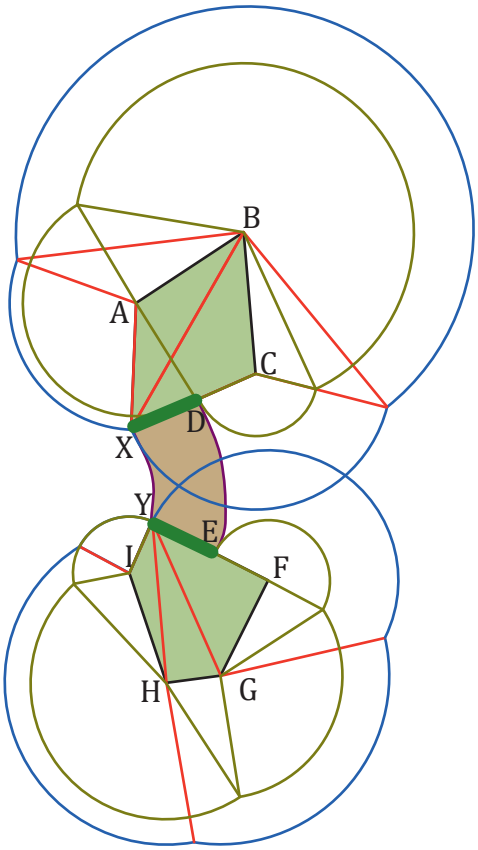
左图：绿色内弧线代表前翅的亚种群边界，拼接线为 XD。右图：同样，后翅的亚副本边界为 YE 拼接线。

渠道

我们需要确保这两条子通道不会重叠。但我们还有一个附加条件：我们必须能够将 XD 和 YE 这两条拼接线一上一下地折叠起来。这第二个条件是拼接线的全部意义所在，但我们如何才能保证这一点呢？这个条件可以转换成一个等价但更熟悉的限制条件：我们必须能够画出一个宽度不变的连续区域，一端为 XD，另一端为 YE。该区域的宽度与 XD 和 YE 的长度相同。我称这种区域为河道。

河道是一种特殊的河流，它的终点是分水岭。我们习惯于将河流的终点设置在纸张的原始边缘或形成一个封闭的环路。但第 67 页的示例表明，河流的终点可以是一条连接线--这发生在河流的一端。其他的河道可以在两端都有一条连接线，这就是我们想要的连接前翼和后翼的河道。这种类型的通道是一条将两个树冠连接起来的长条，形成一个拱形（我喜欢想象小动物沿着小路从一个副树冠走到另一个副树冠，但它们需要一个最小的路径宽度来绕行）。

因此，让我们把这些子坎放在纸上，然后在连接线之间画一条通道（我们可以把它们移近一些，但为了说明通道，特意把它们分开）。请注意，子通道不能重叠，因为它们显示了分界线施加的最小间隔。另一方面，我们可以忽略蓝色显示的原始襟翼，因为它们显示的是整个襟翼的外侧，只与襟翼外侧的其他襟翼相关。事实上，原始顶篷之间的重叠越多越好，因为重叠区域显示了使用拼接线而不是拼接点可以节省多少纸张。



两个不能重叠的子机舱罩由一条通道连接。整体形状的极限--原始顶篷（蓝色）和通道的结合--是前翼和后翼整个襟翼的大顶篷。

安排（最后）

我们需要灵活处理通道的形状，因为我们还不知道任何子通道在纸上的位置。在最终确定排列方式时，我们需要布局的对象是：

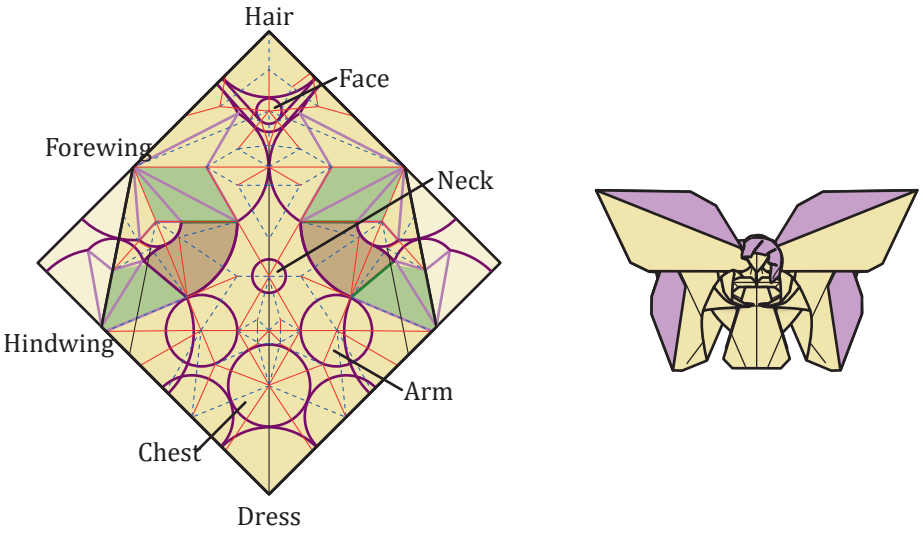
- 圆形 - 每个叶瓣一个。
- 河流 - 每个枝条边缘一个。
- 树冠--未通过接合线与另一个树冠连接的每个树冠一个。
- 子通道 - 通过接合线与另一个树冠连接的每个树冠一个。
- 通道 - 连接两个冠的每条接合线一个。

这些对象的排列与树状理论大致相同，只是形状更笨拙。如前所述，我们还没有证明，只要简单地排列这些对象，使它们不重叠，就能保证可折叠性。但这是一个很好的起点。

下图是 Psyche 的最终折叠模型。后翼的形状略有简化，以便更好地融入正方形中，原角上的纸张并没有浪费，而是用于换色。值得注意的一点是后翼顶篷和手臂圆环之间的重叠。这样做的结果是手臂和后翼比预期的靠得更近。这些重叠总是可以 "消除 "的，只需在适当的位置添加一条或多条河流，而无需改变纸张的折叠方式。

过去，我总是在 "事后 "进行这种修改，但我决定在这里保留它，因为它反映了我设计模型的真实方式。这也提醒我们，看似违反规则的做法其实往往没有问题，只是做了与规则目的不同的事情而已。我们不应该局限于现有的规则，而应该不断探索，创造出自己独特的折纸设计。

在此，我衷心希望你喜欢使用天篷理论，并希望它能让你拓展设计的类型。但最重要的是，不要止步于此--不断增加新的和创造性的方法来发展这一理论。



左图：Psyche 的折叠模型，有牙冠（绿色）和牙槽（棕色）。

NOTE

读完这一章，有些人可能会认为我花了太多时间来思考如何折纸的理论。这些人显然是对的。

MINOTAUR

弥诺陶洛斯是公牛和人类的混血怪物。该模型只使用正方形的一面，因此您可以选择多种合适的纸张。最好的选择是能帮助纸张保持形状，例如覆盖一层铝箔的纸张。

睡前故事

折纸设计师有时会撒一个小谎。我们说我们的设计是精心制作的，描述了所有使用的设计技巧，给人的印象是制作一个小小的纸模型需要花费数小时的紧张脑力劳动。这是一个很好的故事，因为它鼓励读者去思考，如果他们研究技术的时间足够长，他们也会拥有创造自己的折纸模型的超能力。老实说，并不是所有的设计师都会有这样的想法，对有些人来说甚至是真的。

然而，这种说法忽略了一个重要的事实。虽然学习技术是设计的重要组成部分，但没有哪个设计师会有意识地考虑创作的方方面面。是的，你可以说这是潜意识在起作用--我们的 "直觉"--但我认为设计师需要接受某种脆弱性，承认在设计过程中有许多计划外的部分。我们经常隐藏这些无意中发现的瞬间，也许是因为它们打破了折纸设计可以归结为纯数学规则的幻想，这些规则完美地规定了所有特征如何归位。但我最喜欢这些瞬间：感觉就像发现了一个绝妙的秘密，能偶然发现它真是一件令人开心的事。这就好像你在与纸张合作，让它引导你找到它想要的形状，而不是拼命给它强加一个精确的形式。

这并不是说，在数字计算软件的帮助下，不可能创造出上述每一种启示。现代软件功能强大，而且在不断改进，但最好的折纸体验并不来自于此（值得庆幸的是，人类经常将计算能力投入到比制作纸人更崇高的事业中）。如果你想找到属于自己的快乐时光，我没有更好的建议，只能建议你尝试一下设计。就像所有的教育一样，纯粹的实践是无法替代的，重点应该放在创造性的旅程上，而不是目的地。但作为一名教师，我知道速成的诱人形象永远存在于学术学习的每一个角落，因为所需的时间投入是一项挑战。

或者，用仅占 10%的字数来概括上述内容：折纸既是一门艺术，也是一门科学，我们不要妄自菲薄。所有的折纸设计都没有终极算法，如果有的话，我认为这会破坏很多乐趣。

改变命运

拥有这些幸运的机会与众所周知的 "偶然"（或 "试错"）设计方法不同，后者是从涂鸦中产生的。它不是等待着扑向文件的侥幸，而是你通过谨慎使用其他方法试图从纸上得到的东西。此外，我说的不是偶然设计出一个完整的模型，而是充分利用途中出现的所有短暂的顿悟。

发现并利用这些瞬间，与给它们提供展现自己的机会同样重要。在这里，经验也是一笔重要的财富，因为它意味着令人愉快的结构是熟悉的，可以很容易地识别出来。

要理解我的意思，不妨看看我所说的一个例子：牛头人的设计路径呈现了一系列这样的幸运时刻。

不可思议的冒险

我的大部分绘画作品都是从有意识的角度出发的：我知道自己想要表现的主题（在主题范围内有合理的变化余地）。老实说，我不得不承认，我并不完全确定《牛头怪》的创作是否如此。我可以肯定的是，一开始我只是用一些简单的 22.5°形状来尝试塑造一个人形。这可能是我对大量盒状褶皱人形图的一贯反叛。盒状褶皱对人形很有诱惑力，原因有很多：

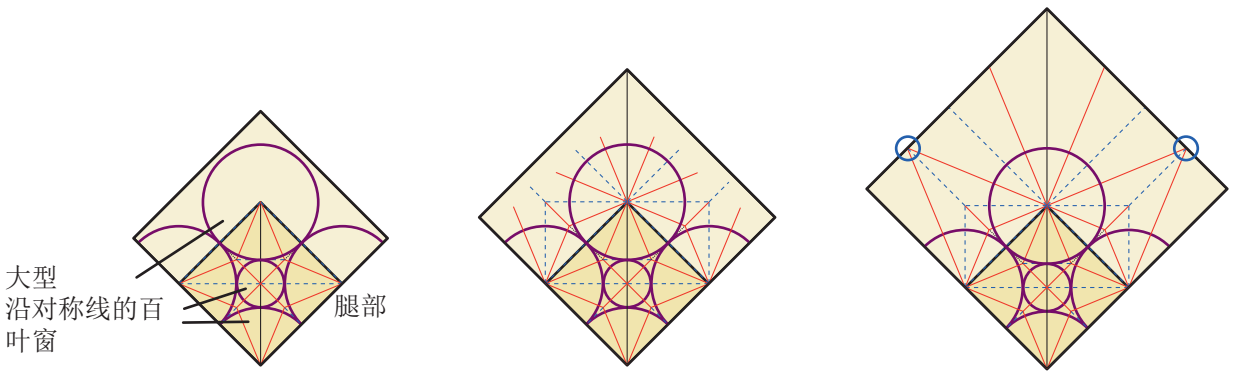
- 传统的底座都没有适当的襟翼排列，而箱形褶皱却有成熟有效的排列方式。
- 箱形褶皱可以让设计师精确地指定四肢的长度。
- 箱形褶皱提供了充足的褶皱，可以创造出细节，例如面部或手指上的细节。
- 在箱褶模型上嫁接新部件通常比较容易。
- 近似矩形的四肢和躯干可以通过成对的平行线来近似。

最后一点的 "几乎 "正是许多盒状褶皱人体的致命弱点。对我来说，盒状褶皱一般都显得过于矩形和无机（这一点在其他题材中经常被忽视，但人体太熟悉了，无法摆脱）。将矩形的一端变细也不太合适，因为这样纸张就会在本应更薄的地方增加层次。这就是为什么我总是很高兴看到 22.5° 的人形绘画。但这种几何形状的改变并非没有缺点，尤其是上述其他四点！我不得不说，箱形褶皱并没有错，而且通常还有其他很好的理由。我只是认为，我们需要在复杂和超级复杂的题材（尤其是人形题材）上有更多的变化。

驯服野兽

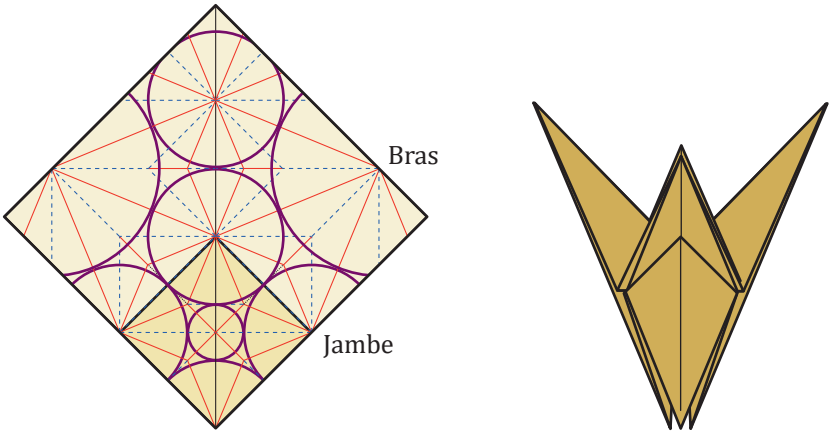
如何通过使用 22.5° 几何形状来缓解这些问题？为了确保有足够的细节，在模型前部设置一些襟翼是很有用的，如果襟翼足够大，就会有多种用途。我们可以通过点将其中一些分开，以便在需要时获得更小的细节。因此任务并不艰巨；我们需要的只是一个带有大型前挡板的底座。即使我们不能直接从传统底座开始，我们也可以很容易地嫁接到底座上，从而获得我们需要的东西。像往常一样，从最大的襟翼开始是合理的，对于人形来说，最大的襟翼通常是腿部。在对角线对称的正方形底部放置一个鸟形底座似乎是个不错的起点--见下图。

然后，我们可以将褶皱沿径向延伸到嫁接区域，如下图中央所示。在最简单的安排中，这些线条将延伸到原始边缘。但具体延伸多远呢？右图显示了嫁接区域大小的自然上限，因为这是在褶皱开始重叠之前最大的选择。这一点值得牢记，因为它决定了所有褶皱的位置。事实上，这种结构在复杂折纸中比较常见。



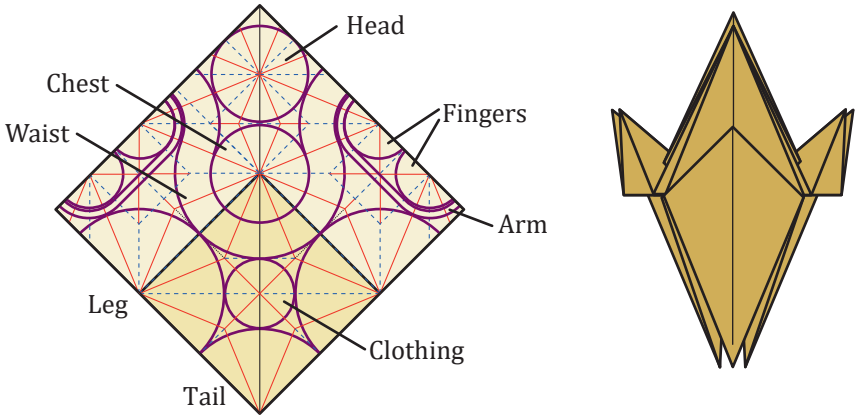
左图：正方形一角的鸟基。
中间：褶皱在嫁接区域的径向延伸。
右图：在圈点处没有褶皱重叠的最大可能嫁接。

通过折叠这个 CP，我们可以看到底面是有希望的。上一页中的圈点不在对称线上，因此如果我们将它们作为襟翼的中心，就会得到一个非轴向的底座。如果我们想把这些襟翼做成手臂，这是件好事，因为这样可以为肩膀留出足够的宽度（许多轴向和盒褶人形底座都会浪费纸张，因为手臂襟翼必须穿过轴线和手臂起始点之间的距离）。我们可以再次从这些手臂的末端向径向延伸一些线条。如下图所示，这样就能创造出相当美观的褶皱图案。



左图：从所有瓣片向径向延伸的额外褶皱。
右图：折叠后的底座。

这个底座是个很好的发现，但在制作人形时存在一个问题：臂瓣太长了（即使我们承认对一些非常厚重的奇幻生物有一定的艺术许可）。因此，我们不应该把嫁接延伸得这么长。让我们回过头来看看，在保持基本布局不变的情况下，将嫁接区域缩小一点会发生什么。



左图：较小移植体的相应模型。几个部分已被临时标注。右图：折叠的底座。

使用较小的移植物意味着手臂末端的部分有多个分段，因为之前相交的两个山形褶皱之间现在多了一段距离。为了简单起见，我们将这段距离分为两点，但它也可以被分成三段或更多部分。这是一个了不起的发现，因为我们可以得到没有额外褶皱、额外嫁接或尖端分裂的手指（或其他手部细节）--这一特性是偶然出现的！

但是我们在另一个方向上走得太远了：手臂部分现在太短了。因此，理想的手臂移植长度应介于这两个极端之间。

但是，当移植区的大小发生变化时，改变长度的不仅仅是手臂。当移植区域的大小增加时：

- 手臂长度增加。
- 胸廓增大
- 腰河宽度减小。
- 手指长度减少
- 头部缩小

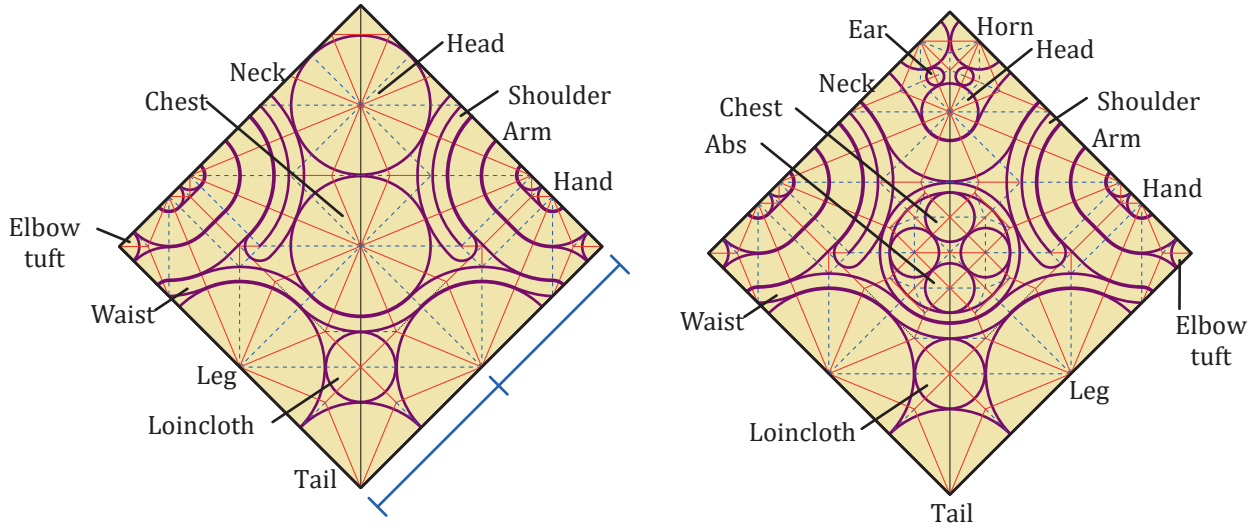
此时，我们可能会怀疑是否存在最佳点；例如，为了获得足够长的手臂，我们可能不得不将头部皮瓣做得太小。当我们将多个引用与同一个变量（在本例中是指移植的大小）相联系时，经常会出现这种类型的约束。在数学术语中，我们说只有一个自由度。当只影响几个特征时，一个自由度往往就足够了，但这里有五个自由度。

此外，最理想的是能有一种非任意的方法来确定接枝的大小，以便获得一个简单的折叠序列来寻找参考。另外，为了满足我们对美观的追求，我们希望所有的折叠都能与我们现有的一些 22.5°几何图形在某种程度上协调一致。我们的要求过分吗？

跟随主题

这是另一个奇妙的发现：用最简单的参照物--正好是纸张边缘一半的位置--就能得出理想的排列。

结果发现，胸前的襟翼适合做四点分割，有足够的纸张来制作轮廓分明的肌肉。头部也有足够的纸张来制作角和其他特征。更重要的是，生角处未使用的纸张在手臂襟翼的一半位置，可以用来制作一个小细节，比如肘部的一簇头发。



左图：通过使嫁接的宽度与鸟的原始底座大小完全相同，可以制作出人形。
右图：牛头人的最终折叠模型。

如果腰布的襟翼能从原边开始，以便更换颜色，那就更好了（但这是我提供的为数不多的襟翼之一，只能怪我自己）。胸部和肩部不必要的长河有点效率低下，但由于它增加了躯干的体积，你可以说这不是坏事。

所有这些想法都是在短短几分钟内完成的，不一定按照这里的顺序排列。设计这个牛头人的过程快得令人难以置信，不是因为我有什么特别的技巧，而是因为有很多巧合同时发生。但正如 19 世纪的一句谚语所说："我练习得越多，就越幸运"。

HYDRA

由于每个标题都比较详细，而且折叠方式相同，因此这些图中有很多重复的步骤，包括嵌套重复（重复中的重复，重复中的重复等）。请记下要求您重复的步骤和需要返回的步骤，以免迷失方向。

SCORPION

对于这个模型，您需要折叠一个 37×37 的网格，折叠方法有多种。这些说明展示了一种只涉及折叠的方法，它在所需的图表数量、清晰度和实现最有用的山谷/山峰折叠方向之间提供了很好的折中。在此，我们要感谢罗伯特-兰（Robert Lang）创建了 ReferenceFinder，它帮助我们找到了第 4 步中使用的参考资料。您可以在他的网站 langorigami.com 上找到这个有用的工具。

如果你想使用自己的序列，请跳过步骤 2 至 18。

SCORPION

BEHIND THE DESIGN

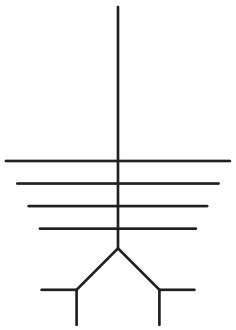
我最喜欢折纸设计的一点是它没有竞争性。由于主观因素太多，我们无法对所有作品的质量进行有意义的排序。尽管如此，设计师们有时会追随潮流，并试图通过对某一主题提出自己的观点来超越对方。一般来说，随着时间的推移，设计会变得越来越复杂，因为发展一个主题最明显的方法就是增加细节。

当下流行的一种趋势是画一只蝎子，蝎子的腿越来越长，一直延伸到身体的后部。对于设计师来说，这自然是一个好题材，因为创造多条相邻腿的最简单方法就是在每条腿上重复相同的折叠模式，使它们的长度相同。因此，设计师在设计这些腿时必须比平时多花一点心思。此外，设计者还可以选择添加一些细节，表现不同种类的蝎子。在这只蝎子身上，我加入了自己最喜欢的元素，在加入许多特征、效率和折叠难度之间取得了平衡。

近 100 步的折叠顺序看似冗长，但与其他类似的蝎子设计相比却毫不逊色。步骤的数量是通过优先考虑简单性而减少的。下文将通过研究该模型的三个主要方面来证明这一点：改变腿部长度的难度、背部折叠的方式以及毕达哥拉斯伸展的加入。

可变腿长

像往常一样，我们可以通过考虑一棵蝎子树来取得进展，这棵树包含了我们所满意的最少数量的特征。

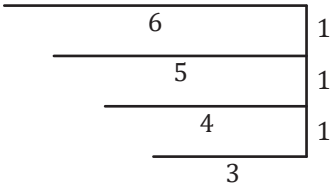


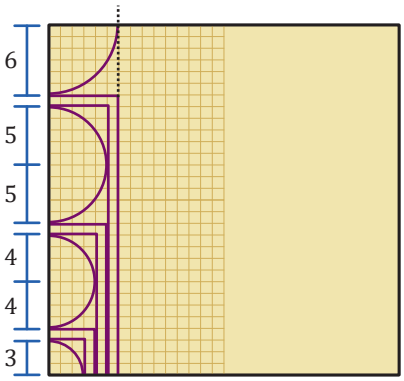
蝎子的第一棵树。目前还没有最终确定相对长度。

蝎子的腿要比尾巴或爪子细得多。因此，我们需要主要从纸的边缘而不是中间折叠蝎子腿（蝎子并不以颜色著称，因此我们不需要从边缘分配纸张来做其他事情）。

为了简化操作，我们应该确保蝎子腿之间的间距相同。这些空隙将对应最终折叠图案中河流的宽度，也是树节点之间的最短距离。创建几条长度相同的河流的最简单方法是使用箱形褶皱（如果我们选择为蝎子上腹部的硬节（tergite）制作褶皱，这种方法也会很有用）。这意味着我们希望树的所有长度都是这个单位长度的整数倍。

因此，相邻两条腿的长度之差也必须是这个单位长度的倍数。因此，为了保持尽可能小的差值，树腿的长度最终将是连续的整数。相对于单位长度，初始树腿长最接近的整数近似值是 3、4、5 和 6。只要稍加尝试，我们就能为这些襟翼找到一种实用的圆/树排列方式。



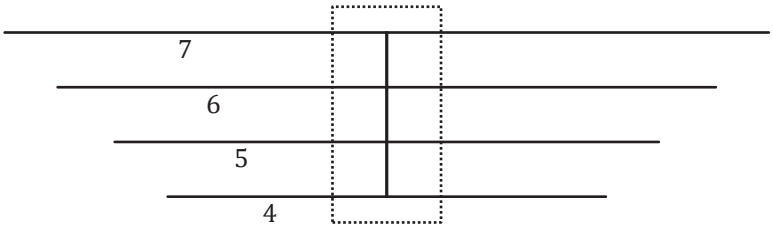


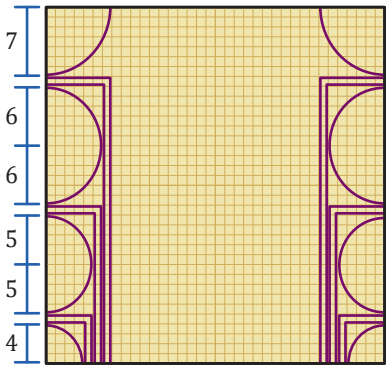
左图： 四肢着地的树木（长度为 3、4、5 和 6）。
右图：树的圆圈/河流排列。这种排列方式在树腿和纸的其余部分之间形成了垂直分隔，这正是易折折纸的特点。

事实上，只有当襟翼的长度不同时，才有可能出现这种变化，因为襟翼两端（圆心）之间的距离都是相等的。另一方面，如果瓣片的长度都相同，但两脚之间总是有一个单位的间隙，那么瓣片两端之间的奇数距离就无法让山峰和山谷交替出现，这就会使折叠图案在没有进一步工作的情况下无法折叠（例如，将网格数量增加一倍，使每个距离都是 2 的倍数）。关于偶数或奇数距离的问题，我们将在后面的几页中详细讨论。

在上面的例子中，最短的一条腿只有 3 个单位长，实在是太短了。请注意，上面的树状图没有考虑腹部的宽度，腹部会从腿部突出，使腿部在实际中看起来比这些数字更短。如果我们现在决定最终使用

尽可能小的身体宽度，那么重叠部分将为 1 个单位，因此让我们在上述腿长基础上增加 1 个单位。



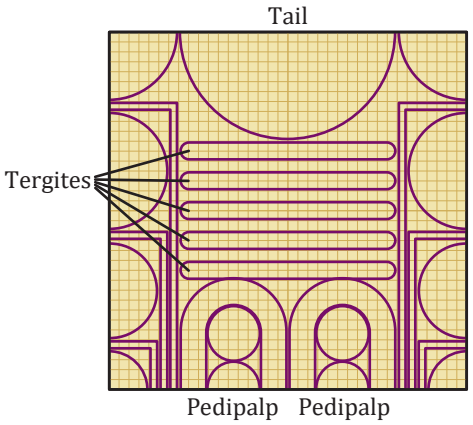


左图：四对腿（长 4、5、6、7）的树，考虑到腿的区域隐藏在腹部下方。
右图：树的圆圈/河流排列。这种排列需要一个 36×36 的网格。

添加褶皱

这就在中间留下了一块区域，似乎可以容纳顶部的尾巴和底部的两只爪臂，包括爪子（称为足爪）。我们将为这些部分添加圆圈和河流，幸运的是，这些圆圈和河流的大小似乎适合这些身体部位。这样，在纸张的中央，沿着蝎子的背部，就有一大块区域没有填充。我们不需要浪费这张纸，因为我们可以用它来做几个褶皱来表现蝎子的鳞片。在圆形或河形布局中，褶皱可以用一个单位长度的宽瓣来表示。这些褶皱可以用来填满所有剩余的空间--在本例中，有空间容纳五个叶片（请记住，我们仍然需要在相邻叶片之间留出一个单位的空间，以便沿腹部将它们分开）。

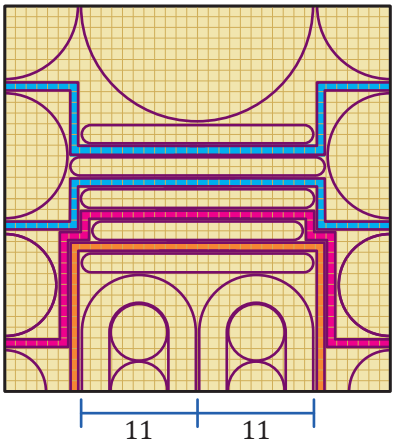
事实上，这也是在初始树中包含最少元素的优势之一，因为我们现在可以选择只添加纸张自然容纳的元素。一般来说，这样的设计效率很高，因为这些功能都能精确地融入纸张所提供的可用空间。我们所付出的代价是，我们失去了精确指定模型包含哪些功能的自由，因为纸张可能没有空间容纳我们想要添加的所有功能。



圆圈/河流布局，包括尾部、足瓣和鳞片的大致位置。
尾、足瓣和鳞片的大致位置。

毕达哥拉斯伸展的加法

然而，在前一个 CP 中，河流并不完全适用。一方面，腿与腿之间的河流应该与叶片之间的河流相同，因此我们需要将它们匹配起来。另一方面，足瓣应该与前肢相距一个单位，因此我们需要一条新的河流来分隔这两个元素。让我们通过连接相应的河流来解决这两个问题。



将两腿之间的河流和两叶之间的河流连接起来后形成的
圆圈/河流排列。

蓝色河流的效果很好，但橙色河流没有很好地填满前腿和脚掌之间的空间。这意味着有一点空间被浪费了，但这并不妨碍排列的有效性--这个空间的宽度是 2 个单位，所以宽度为 1 的简单折叠就可以隐藏这张纸。

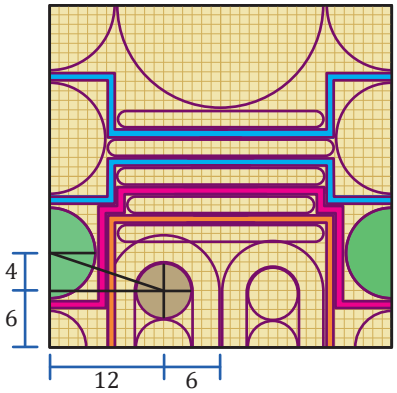
事实上，每只脚掌都是对称的，这就更成问题了：因此，无论瓣的长度是多少，它的总宽度都必须是偶数。然而，可用空间受到橙色和品红色河流的限制，只剩下 11 个单位。

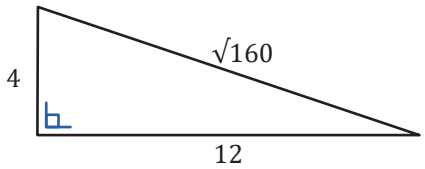
如果我们能从这种排列中多抽出一个单位就更好了，这样每只足爪所需的纸张宽度就是 12 个单位，而足爪的长度就是 6 个单位。如果我们假定能以某种方式得到一个额外的单位，这就决定了方程上圆的中心位置。

Le pédipalpe (la pince supérieure) doit être à 6 unités à partir du bord inférieur et 6 unités à gauche de la ligne verticale centrale. C'est le cercle brun dans l'image ci-dessous.

Le point essentiel est que la distance entre le centre de ce cercle brun et le centre du cercle vert doit être au moins aussi grande que la somme suivante : la longueur du pédipalpe (6) + la largeur de la rivière orange (1) + la largeur de la rivière magenta (1) + la longueur de la patte verte (5) = 13. Mais le centre du cercle vert n'est qu'à 12 unités du bord brut gauche, nous ne pouvons donc pas obtenir cette distance en considérant uniquement la distance horizontale.

Qu'en est-il alors de la distance diagonale ? La distance réelle entre les centres des cercles est l'hypoténuse (grand côté) d'un triangle rectangle et peut être calculée à l'aide du théorème de Pythagore, en utilisant à la fois les distances horizontales et verticales entre les centres des cercles. Après un rapide calcul, nous constatons que la longueur est de ≈ 12,65, ce qui est malheureusement toujours inférieur aux 13 dont nous avons besoin. Même en diagonale, il n'y a donc pas assez de place.

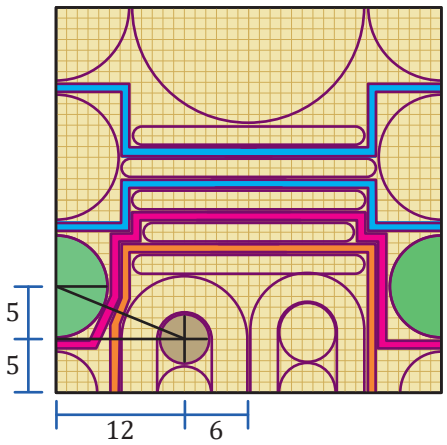


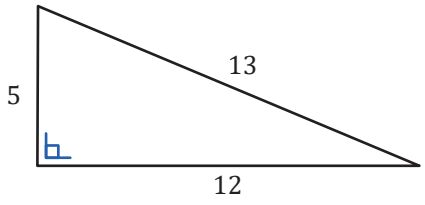


La distance entre les centres des cercles vert et marron est $\sqrt{(12^2+4^2)} = \sqrt{160} < 13$.

Et si nous déplacions le centre du cercle brun d'une unité vers le bas ? La distance verticale entre les centres des cercles vert et marron passe alors à 5, ce qui donne une nouvelle hypoténuse d'exactement 13 unités. Nous sommes tombés sur le triangle 5-12-13, qui est un exemple de **triangle de Pythagore** - un triangle rectangle dont chaque côté est un nombre entier. En déplaçant le pédipalpe vers le bas, nous avons également supprimé le chevauchement entre le pédipalpe et le lambeau du tergite le plus bas, ce qui, vous l'avez peut-être remarqué, s'est glissé dans le diagramme ci-dessus lorsque nous avons agrandi légèrement les lambeaux du pédipalpe.

L'utilisation d'une distance diagonale comme celle-ci pour augmenter la distance entre les points s'appelle un étirement pythagoricien, et si un triple pythagoricien exact est utilisé (comme ici), on parle d'un étirement pythagoricien parfait. Personnellement, je trouve que les **étirements pythagoriciens** qui ne sont pas parfaits sont inutilement compliqués (c'est beaucoup plus de travail d'obtenir des références pour plier un **étirement pythagoricien non parfait**). pour plier un étirement pythagoricien non parfait, et la structure contient moins de plis axiaux). Dans presque toutes les circonstances, les volets peuvent être arrangés de manière à ce qu'un triple Pythagore exact fonctionne.





En déplaçant le cercle marron d'une unité vers le bas, la distance entre les centres des cercles vert et marron est maintenant de $\sqrt{(12^2+5^2)} = \sqrt{169} = 13$. Il n'y a plus de cercles ou de rivières qui se chevauchent.

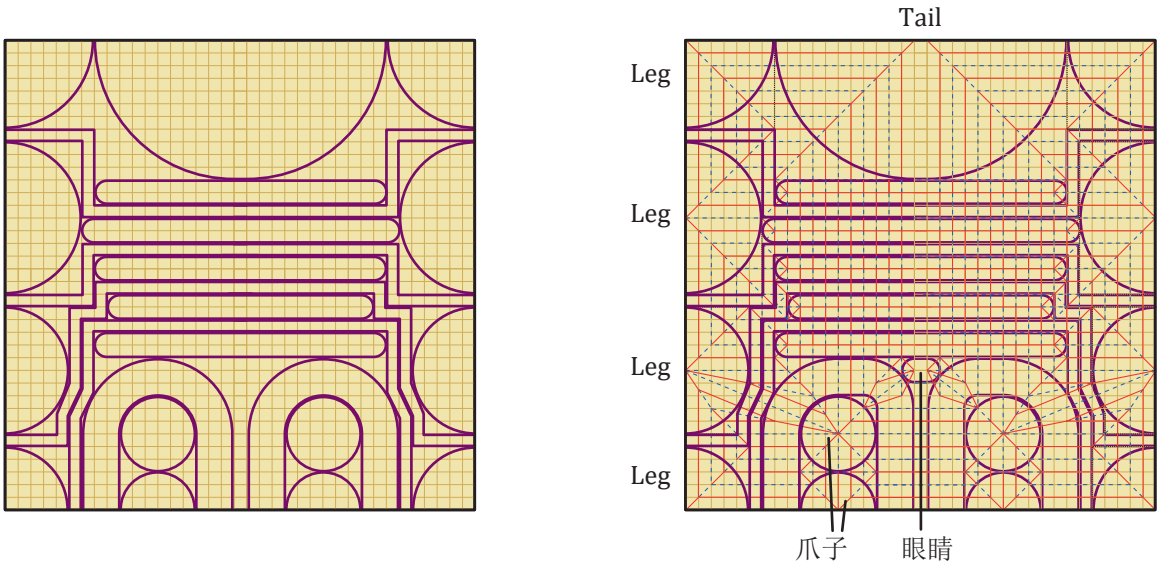
均等问题

但是，在这种新的排列中出现了一些不理想的情况：棕色圆圈现在距离底边有 5 个单位的距离。这个距离相当于每个夹子长度的两倍，因此应该是一个偶数（如果我们坚持使用网格）。棕色圆圈的垂直位置由绿色圆圈的中心和 5-12-13 三角形的额外 5 个单位决定。即使两条腿的长度不同，这些距离的总和也总是奇数。这样，底部就有奇数个方格来完成偶数网格，但我们想要的是偶数。我们目前的 36 个单位的网格无法解决这个问题。

不过，我们还有最后一招：我们可以在网格中多加一个单位。这并不是没有代价的--折叠 37×37 的网格并不是很正统，但它让我们的夹具之间的距离相等，从而解决了奇偶性问题。事实上，它还能更进一步：额外的空间让我们可以将前腿的长度增加一个单位，这样它就可以接触到周围的河流了。

通过在网格中增加一个单位，我们在棋盘中央多出了一条竖线。这样一来，蝎子的身体就变宽了，这意味着在这条竖线的两侧现在有两条轴线。这很不寻常，但没有明显的缺点。

最终的布局如下左图所示。现在所有的圆和河流都可以使用了，可以用来折叠天蝎座的底座。在最终的折叠模式中，我还使用另一个毕达哥拉斯伸展法为眼睛添加了一个额外的挡板。为了防止有人检查，我还要提一下，天蝎座图中的叶片序列并不完全使用这些折叠，因为虽然 CP 很好地说明了瓣膜结构，但折叠起来却相当困难。



左图：天蝎座圆形和河流的最终排列。右图：完整的折叠图案。

我们不妨先讨论一下均等问题。在箱褶模型中，我们几乎总是在山谷和山峰之间交替，前腿和后腿处于同一"山谷 "水平，尽管它们之间相隔 37 个单位--一个奇数，这难道不奇怪吗？原因在于毕达哥拉斯伸展打破了通常的交替。因为三角形的高度是奇数，所以奇偶性被颠倒了。

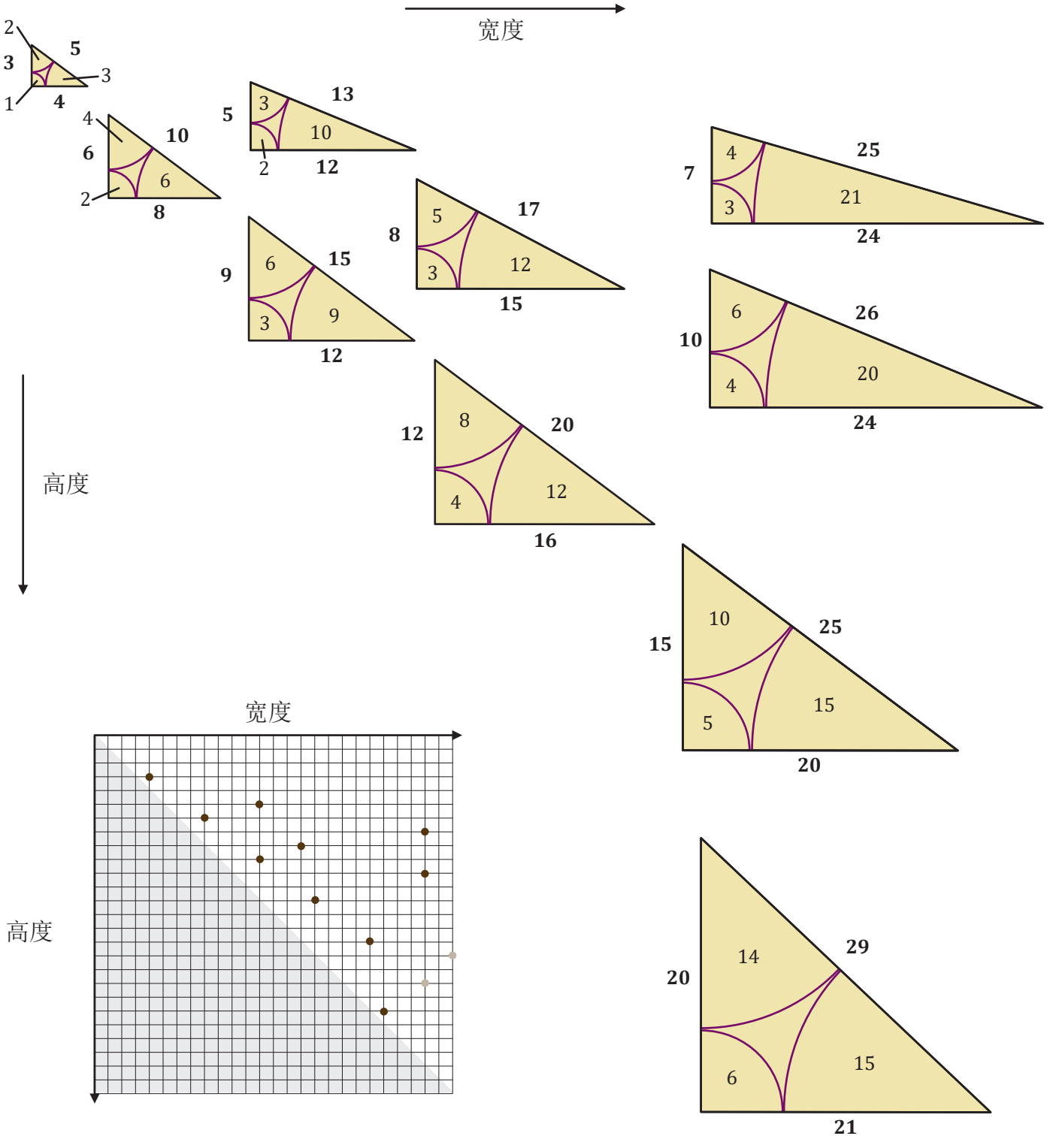
大多数对称的盒褶图案都使用偶数网格，这样其中一条网格线就正好位于中心。但是，每当毕达哥拉斯拉伸使用原始毕达哥拉斯三边（三边长度的最大公因数为 1 的三角形）时，其中一条垂直或水平边必须是奇数。在这种情况下，最好使用奇数网格数。每个非质数毕达哥拉斯三项式都只是质数毕达哥拉斯三项式的倍数（正如每个非质数都可以表示为质数的倍数一样），用质数毕达哥拉斯三项式乘以偶数就可以避免这个问题。另一种解决奇偶性问题的方法是使用偶数个原素三元组，这样奇偶性就会反转偶数次。

常见三元组

虽然它们可以被计算出来，但拥有一份有用的勾股定理三角形列表还是很有用的。

下面是斜边小于 30 的三项式。我从未见过使用超过这个数量的设计，但不要犹豫。

同时还显示了圆弧的半径，如果将三角形折叠成兔耳朵的形状，这相当于三个瓣的长度。



AQRABUAMELU

Aqrabuamelu　是巴比伦神话中的一种强大生物。它们拥有人类的头部、躯干和手臂，以及蝎子的身体。虽然它们通常以男性形象出现，但我在这里选择了女性版本。

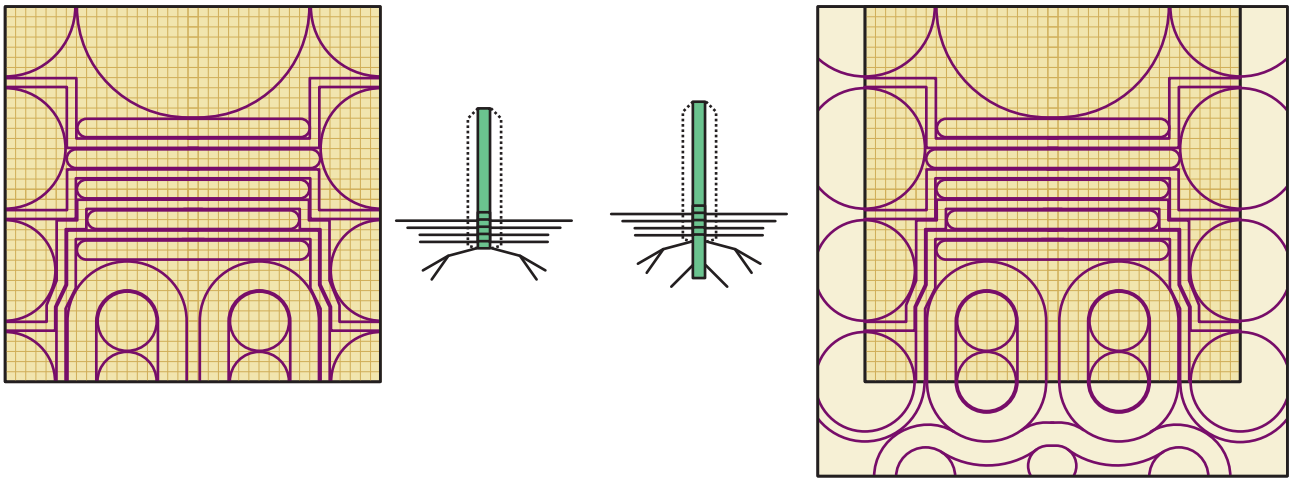
可加性

有些艺术形式具有可加性：你可以通过独立调整和修改个别部分来发展同一件作品。如果你不喜欢你的第一张铅笔素描，那就画出来；或者如果你的雕塑需要更多材料，那就添加粘土（我相信还有更多细微差别，但如你所见，我既不是画家也不是雕塑家）。

折纸就没有这个优势。你不能简单地在现有的折纸模型上添加新的特征而不影响整个模型（至少纯粹的折纸不是添加式的：如果你愿意，你可以很容易地用另一张纸来添加纸）。在折纸模型上添加元素最复杂的方法是嫁接，但这种技术有几个复杂之处。嫁接：

- 使原模型的现有部件变厚。
- 可能导致颜色变化
- 改变折叠基准
- 使模型的效率降低，除非您能使用所有增加的纸张（几乎肯定不能）。

最后一点是许多嫁接可能性的致命伤：嫁接适合在许多不同的地方添加小细节，但不适合在一个地方添加一个或一组大型瓣片。让我们试着在蝎子身上加上人的上半身，创造出一个 Aqrabuamelu（想想美人鱼，不过是蝎子而不是鱼）来证明这一点。如果我们把新纸嫁接到底部的原纸边缘上，我们最终会在不需要新纸的地方添加至少同样多的新纸。这些新纸有一部分可以回收，但大部分都无法使用。下面的嫁接只产生了一组基本的襟翼，但我们更希望在底部原边有更多的纸，这样会在正方形的两侧产生更多的废纸。其他的嫁接方案，例如在纸张中央添加竖条，也存在问题。



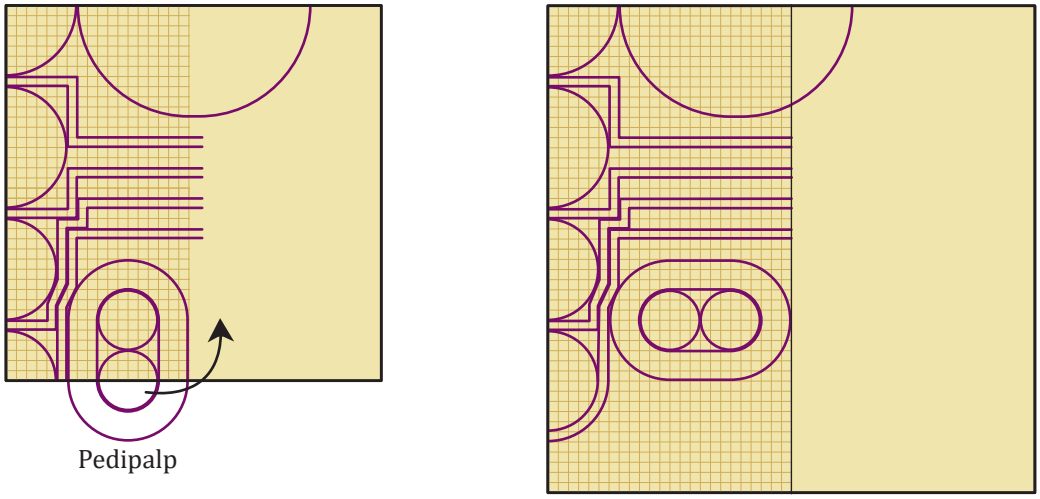
左图：天蝎座的圆圈、河流布局和树。
右图：扩展后的树，包括基本的人类上半身和可能的嫁接。这需要增加 56% 的纸张，其中大部分无法使用。

那么，即使是非常相似的模型，每次进行新设计时都必须从头开始吗？不，我们只需要比标准嫁接少一点直接的方法。相反，我们可以借用模型和原理来大大加快初始设计阶段的速度。我们将看到如何通过借鉴来创造出比上面更有效的 Aqrabuamelu。

偷窃自己

那么，我们可以从现有的天蝎座设计中汲取哪些灵感呢？我们从腿部结构入手，决定采用箱形褶皱。叶片和小的垂直嫁接带是我们最后添加的元素（因为它们填满了剩余的空间），所以我们要去掉它们。像往常一样，我们要做一个对称的设计，所以让我们简化一下，现在只在纸的一半上做文章。

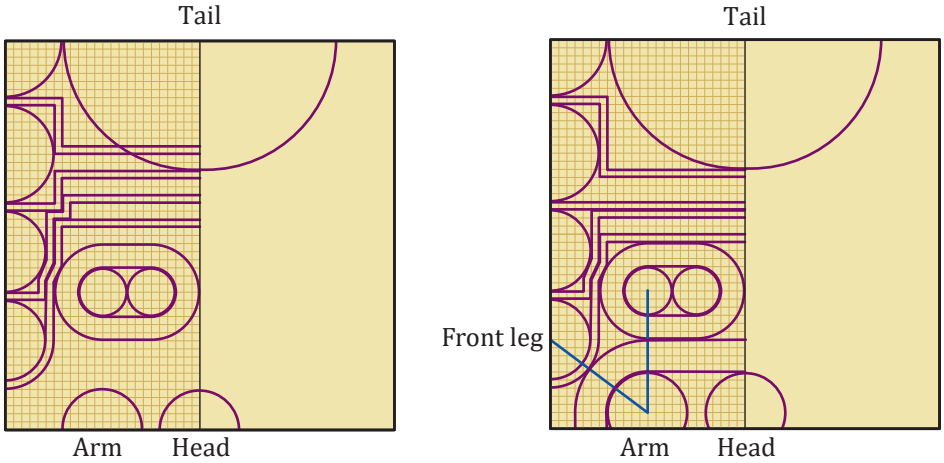
我们需要放大正方形，以容纳更多的襟翼，还需要在底部原边中间附近为人体躯干留出更多空间。我们可以用一个小技巧来回答这两个问题：让我们旋转脚掌，用它来确定对称线的位置。



左：天蝎座左半边的圆圈/河流排列。
右图：两个圆圈的旋转和周围的河流
在叶片底部留出了足够的空间。

放大纸张后，尾翼不再位于中心位置，因此我们可以放大这个圆来填补空间：正方形宽了 6 个单位，因此尾翼将变长 6 个单位。这个放大的圆圈与之前被背部的叶片和河流占据的一些襟翼相交，因此我们要将这些襟翼向下移动，直到没有重叠为止。

至于分配给人类特征的新区域中的纸张，让我们用几个手臂和头部的初始圆圈来填充这个空间。这些需要从现有的河流和圆圈中分离出来，以考虑到腹部。如果我们将手臂的中心点放在左爪正下方距离原始边缘 2 个单位的位置，那么就可以实现完美的毕达哥拉斯伸展--这个点距离左爪和前腿正好是 15 个单位。

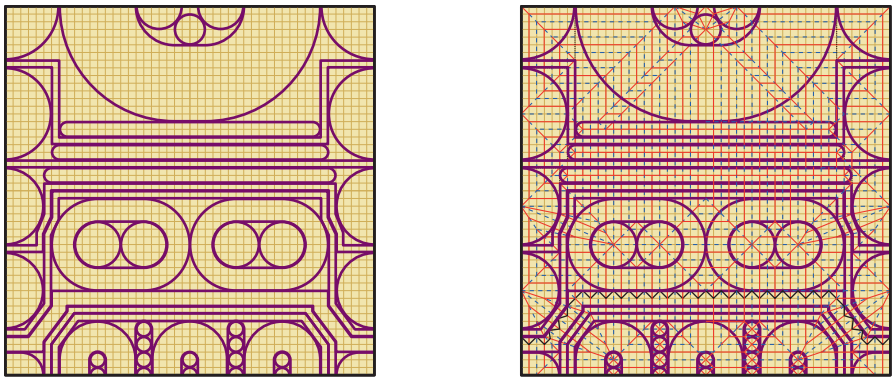


左： 尾部的圆圈扩大了，并为人体躯干添加了新的襟翼。
右图： 我们整理了纸张中间的河流，并为手臂找到了良好的对齐方式。

我们感觉自己离目标越来越近了，而且并没有花费太多的精力；我们只是收获了偷窃前一个模型的好处。但在完成之前，还有一些问题需要解决，还有一些细节需要补充。

首先，原始角落里有少量纸张等待使用。这张纸大约有胸口高，可以用来添加细节。一般来说，我们首先会想到衣服，但如果这个混血生物穿着普通的衣服，那就有点奇怪了。也许我们可以用它来制作一个不那么赤裸的女性阿克拉巴马鲁？然后是头部周围的纸张--在制作折纸头像时，大的襟翼并没有什么不妥；你可以用这些纸张来制作长发，也可以将其分成较小的襟翼来制作面部特征。我们正处于粗制滥造的边缘，如果不利用现有的颜色变化，那就太可惜了，所以我们来做一些头发吧。最后一个问题还是奇偶校验：我们可以用奇数个单位来制作鳞片。如果稍加创造，我们可以在尾部开一个奇怪的缝，形成一个三叉形的刺，然后利用另一个毕达哥拉斯伸展法从这个瓣中提取一个单位。我们可以创造性地弯曲奇妙的生物，这对我们再次有利。

有了这三处改动，我们就可以完成折叠图案--如下图所示.....



左图：Aqrabuamelu 的圆圈/河流布局。
右图：完整的折叠模型

等等，这不是第 123 页所示的折叠模式，如果你折过这种模式，你就会知道它与图示不符。那到底是怎么回事呢？

实用性和复杂性

上图中的 CP 是我在设计该模型与 "天蝎 "模型时所想象的原始模型。我为蝎子绘制了图解，并打算为阿克拉巴马鲁绘制同样的图解。但这个模型就这样保持了大约六个月，在此期间我从未有过折叠它的冲动，更不用说为它绘制图表了。模型的布局并没有什么问题，它也是一个完美的 CP，那我为什么不想折叠它呢？

原因有几个，但要注意的是，这些都是主观上的担忧：

- 款式相当无机（箱褶的必然结果）。
- 设计变得异常棘手。虽然与蝎子相比只增加了少量襟翼，但内部襟翼的数量却增加了一倍。为了在蝎子的一半与人类躯干的交接处实现颜色变化，有一个非常令人不快的混合反褶--这就是 CP 中的锯齿线。
- 我没有耐心折叠大型网格。
- 绘制制作底座所需的水槽图的想法非常令人不快。我一生中只能绘制有限数量的模型，我必须现实地考虑这是否真的值得。这似乎不是一个设计问题，但经验告诉我，如果我不想制作图表，人们就不会愿意折叠模型。

为了使这个模型有效和高效，我把它弄得过于复杂，犯了折纸设计最大的错误（是的，甚至比剪纸还严重）：使设计过程变得简单，却牺牲了折叠的难度。 至少，这是我的看法--也许有些人并不介意折叠上面的 CP。欢迎尝试；你会比我更早折出自己的设计）。

别误会：我喜欢复杂的模型。但上面的 Aqrabuamelu 图案不仅仅是复杂，它还很复杂。我认为有必要将复杂的模型与复杂的模型区分开来，前者是为了创造设计者对主题的想象，而不是因为设计者没有花时间清理自己的模型（并加以改进），而后者则是因为设计者没有花时间改进和清理自己的模型（当然，在这方面我主要是在批评自己）。仅仅因为模型是有效的，满足了树的要求，设计过程就结束了。设计的最后阶段是通过修剪问题来简化模型，直到出现一个更健康的模型。

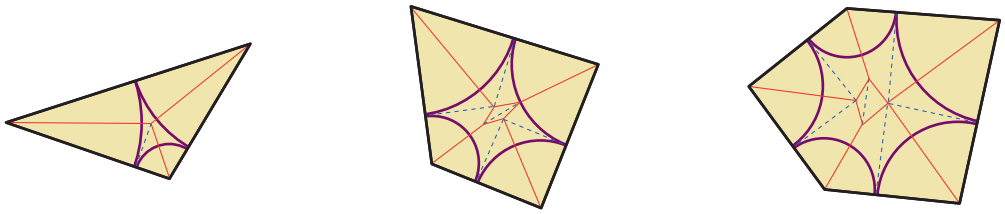
新生活

在许多模型中，这个清理过程都是逐步进行的，但我选择在本章中介绍它，是因为对于这个模型，我们可以使用一种可以（而且应该）在其他地方重复使用的方法来做一些特别了不起的事情。

德博兴

我们的问题来自箱褶。还记得我们最初设计天蝎座时，我们用它来简化事情。但简化必须有条件：对谁简化？方框褶皱是一种设计上的捷径，可以将功能大致放在正方形的正确位置，但我从未提及（甚至从未建议）它是否会让折叠模型的人觉得更简单！

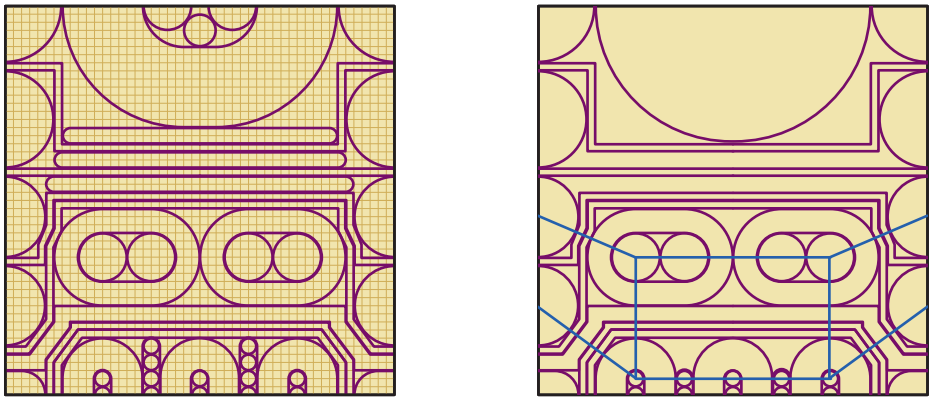
我们将尝试纠正这一错误，去掉方形褶皱，改用圆形设计几何图形--我称这一过程为 "deboxing"。我们将在最近的几对圆之间添加新的轴向褶皱，以创建边缘均为轴线的多边形。这些多边形被称为分子。当分子中的边数较少时，分子是独立的，也很容易折叠：三条边很容易，四条边也可能合适，但一般要避免五条或更多。



三面、四面和五面分子的例子。

但是，我们能否在逆向设计 Aqrabuamelu 第一代 CP 的同时，又不失我们辛辛苦苦达成的安排呢？好吧，大部分情况下，我们会做出一些牺牲，但我希望你们会同意，最终的结果是值得的。

盒状褶皱的主要好处其实是我们最后添加的部分：肩部的叶片和一些小襟翼（我们可以让襟翼在靠近底部原边的地方保持水平对齐，因为底部的带子看起来像一个嫁接，应该很容易折叠）。从设计的角度来看，这些单位长度的小襟翼很容易与盒褶相吻合，但却很难用分子来复制（或者说，至少很难用简单折叠的分子来复制：你可以制作一个怪物分子来完美复制盒褶排列的梯形，但我们只是把问题复杂化了）。
不过，这些梯格是 Aqrabuamelu 最难折叠的部分，所以我们不应该为失去它们而感到惋惜；优先考虑折叠的简易性正是去盒式化的意义所在。我们还将删除网格和尾部分离点（注意，我们是按相反的顺序删除这些元素的，这表明我们保留的原始圆圈从未计入折叠方框中）。接下来，我们将为剩余的襟翼绘制轴向褶皱。

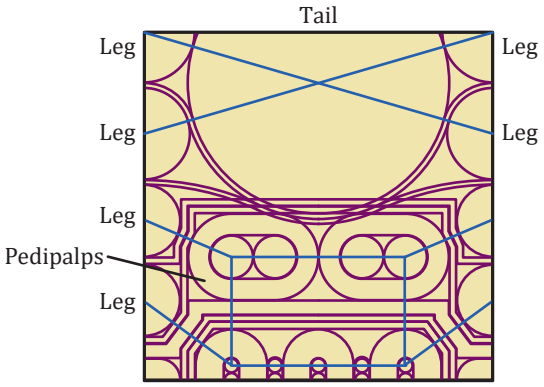


左图：方格褶皱中的阿克拉布阿梅卢圈/河。
右图：网格和一些小挡板已被移除，并绘制了轴向褶皱。
请注意，整个生边都是轴向的。

没有轴向褶皱的大型多边形无法用简单的分子进行折叠，因此我们需要添加轴向褶皱将它们分开。有两种方法可以做到这一点：

- 在圆圈或河流之间的空白处添加更多的小百叶窗。这样我们可以保持相同的布局，但如果我们想让模型更简单，添加百叶窗是一个非常糟糕的主意。
- 移动现有的百叶窗，直到它们相互接触。我们可能还需要调整百叶窗的尺寸，以保留现有的轴向连接。这就是我们要使用的方法，但技巧在于将这两种调整保持在可控范围内，以免对轴造成严重干扰。

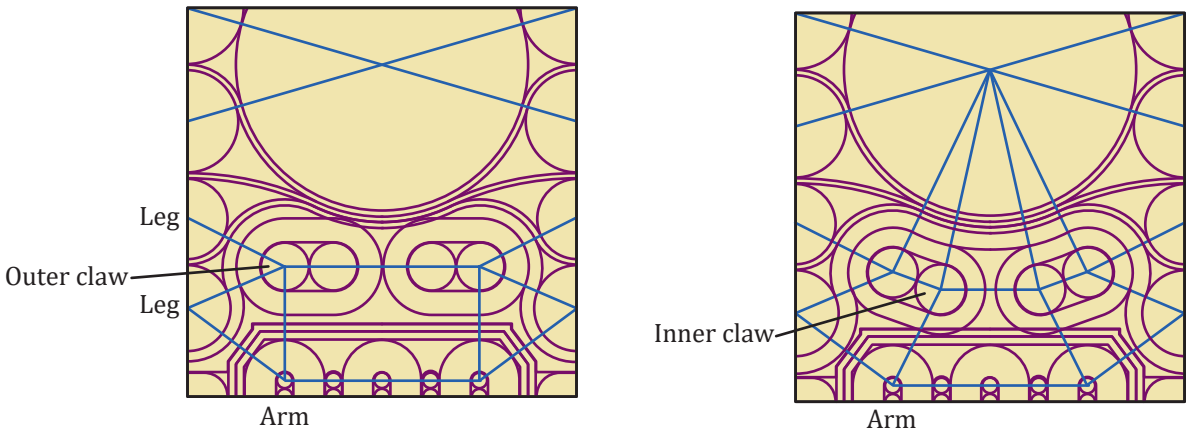
像往常一样，最好先检查大的瓣膜。我们先将尾翼向下移动，形成新的轴向褶皱，将尾部与从顶部开始的第二对腿连接起来（我们还有空间这样做，因为我们已经没有了叶片）。最好的位置是将圆心正好放在顶部四条腿的中间，这样就能形成一个 X 形的轴向褶皱；我们只需折叠两次就能得到四条轴线。我们需要将圆稍稍放大以填满空间（看看你是否能算出这个新瓣的长度，并找到我对这个圆的新位置特别满意的另一个原因）。



尾部下移并略微加宽。这样就形成了四个新的轴向褶皱。虽然这看起来效率不高，但（部分）内部褶皱的存在具有一定的实际优势，尤其是它可以隐藏刺的生边。

现在这个圆圈与足爪重叠，因此我们应该将它们向下移动。事实上，如果我们观察一下轴向褶皱，就会发现一些奇怪的现象：在排列中，外爪更靠近从上往下的第三对足，但在最终模型中，它们应该更靠近最低的一对足。因此，出于多种原因，这一移动可以使排列更加自然。和以前一样，这种调整需要我们稍微修改一下爪子的长度。但是内爪和外爪与尾巴的距离略有不同。为了解决这个问题，我们需要旋转脚爪，使其不再处于水平状态。这样就多了四个轴向褶皱。

通过移动夹钳，我们使内夹钳臂更靠近外夹钳，迫使我们修改轴向弯曲，如下图所示。此外，内夹钳不再接触。这通常是个问题，但在纸的中心，我们需要更大的距离来分隔模型的左右两半，这就是为什么这条线被认为是轴向的。(在图表中，这个距离也被视为轴线--这是一种近似的方法，可以稍微加强立体感，但大多数文件夹都不会注意到）。

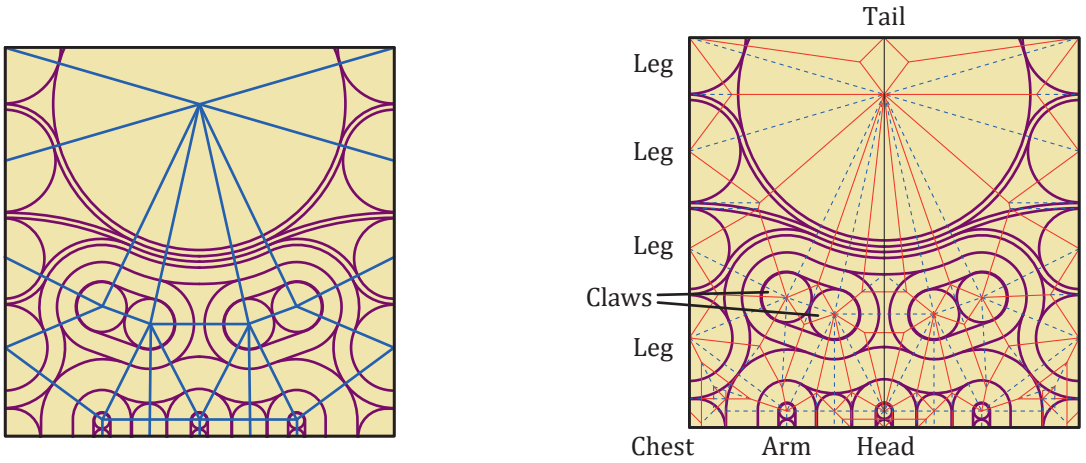


移动和旋转脚爪会产生四个额外的轴向褶皱。

我们只剩下一个分子有四条以上的边了（在上图右侧纸张的底部），所以我们再增加一些轴向折叠来将其分开。同样，这也会稍微调整瓣的长度。如前所述，如果我们在折叠序列开始时折叠原始边缘，就可以将其视为嫁接，并利用它实现与人体皮肤相同的颜色变化。这种边缘嫁接意味着我们可以将折叠边缘视为新的 "原始边缘"，这非常有用，因为原始边缘上的轴向褶皱可以很容易地折叠成壁球褶皱和花瓣褶皱，就像青蛙底座上的点一样（见第 138 页步骤 100 和 101）。这样就能得到下面最终的圆形折叠图案。

结论

这种款式比方形褶皱款式更容易折叠，但是否值得多费周折呢？我的回答是 "是的"，但你必须亲自测试一下：折叠两种款式，看看你更喜欢哪一种。这种比较可能看起来不公平，因为我只提供了圆形折叠版本的图解。但图解不是凭空出现的--你必须找到顺序，而这正是我的意思：折叠盒褶版没有好的顺序。这是设计过程的直接结果，因此也是模型本身的属性。那么，真正的考验来了：一般来说，你是否曾经因为只有模型的 CP 而没有步骤图而放弃折叠模型？我想答案是 "是的"，对所有折叠者来说都是如此。



左图：所有分子现在都只有 3 或 4 个边；所有轴向褶皱现在都被填满（以山谷的形式）。右图：最终的褶皱结构。

Spider

许多奇幻世界中都有蜘蛛，无论是作为药水的成分、巨大的敌人还是恐怖的气氛。

这个模型并不是用来表现某个物种的，而是一个普通的蜘蛛。将它与场景中的其他模型一起展示，可以赋予它一些背景信息！

虽然步骤数并不多（对于复杂的折纸来说），但第 73 步至第 83 步难度很大，使该模型具有超级复杂的地位。祝大家都能顺利完成这一页！

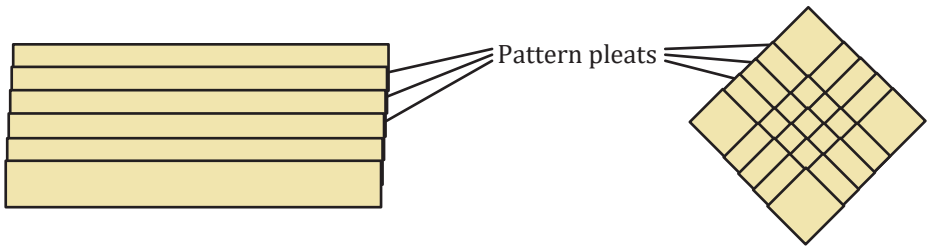
Dwarf Brawler

在许多方面，"争斗矮人 "已经是一个非常困难的模型，但迈克尔的惊人演绎将为您带来更大的挑战。他找到了足够的额外纸张来雕刻手指、更逼真的脸部以及头盔上的几个细节，包括角和一只鸟！您可以在第 182 页了解更多关于迈克尔和他作品的信息。

这都是为了鼓励大家在折叠过程中超越图解，探索自己的变化。但这是一个漫长的过程，我仍在努力！在第 vi 页，您将看到我自己对矮人斗士的硬朗诠释的照片。

魔方

折纸中最受欢迎的领域之一是通过在纸上重复折叠相同的序列来创建几何图案--这些图案被称为 "魔方"。这些图案非常适合用来练习精确折叠，因为在需要统一的模型中，即使是很小的错误也会很明显（而且，出于某种原因，魔方爱好者常常会发现，把模型做得越小越好是一件非常快乐的事情）。



左： 一个非常简单的单向褶皱网格。右图 有两个方向褶皱的简单细分曲面。

虽然很多人喜欢自己折叠魔方，但一些最引人注目（也最复杂）的折纸模型是有代表性的，在设计中的某个地方嵌入了魔方。例如，超级复杂的带鳞片的折纸龙似乎数不胜数。为了区分独立的棋盘格和嵌入代表性模型中的棋盘格，我把独立的棋盘格称为 "图案"，而把嵌入模型中的棋盘格称为 "嵌入图案"。作为模式一部分的每个折叠都是 "模式折叠"（我们将在本章后面看到其他类型的折叠）。

在本章中，我们将介绍几种使用内置模式创建模型的方法。现有的模式有很多，因此我们不会探讨如何设计它们。相反，我们将研究如何将它们集成到模型的其他部分，这往往是比模式本身更困难的挑战。最常见的图案由两个方向的多个平行折叠组成。因此，我们假定目标是在图案中添加一排这样的折线。

如何为模型添加图案？

图案嫁接

在现有模型上添加图案的最简单方法是图案嫁接。具体做法是检查折叠图案，确定图案的折叠位置。在折叠其他东西之前，先在纸上做出所需的褶皱，使其位于正确的区域。完成折叠后，将图案纸视为一张新纸。然后用这张新纸折叠图案。

图案嫁接很简单，但有一个大问题（也很耗时）。如果在设计的最后阶段才考虑任何嫁接，包括图案嫁接，那么所有其他特征的位置都已经确定。这意味着图案褶皱中未用于图案区域的部分会被浪费掉，从而降低了纸张的使用效率。效率往往不是唯一的设计标准，但在图案嫁接时必须考虑到这一点，因为折叠区域较厚、不平整且难以折叠。最好的办法是从一开始就将折叠融入设计中。

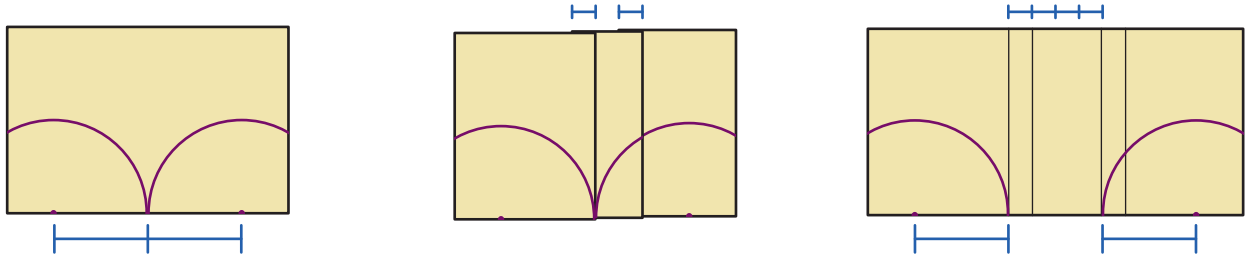
内置折叠装置

没有嫁接的褶皱称为内置褶皱，有几种制作方法。内置褶皱本质上并不高效--这取决于如何实现。在最糟糕的情况下，内置褶皱最终使用的纸张和嫁接褶皱一样多，并且使模型的折叠变得更加复杂。

斗士侏儒 "采用了三种不同的折叠方式。让我们依次看看每种方法，分析它们在各自的情况下为何有用。

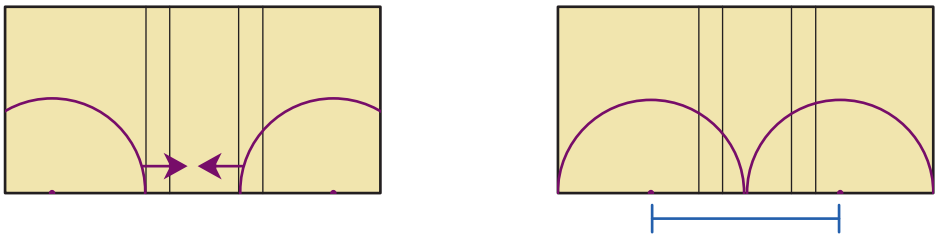
拉伸

让我们先来看看两个边缘瓣之间的褶皱，这在带有嫁接褶皱的图案中很常见。下图显示了增加褶皱是如何增加褶边之间的距离的。从数量上看，增加的距离是褶宽总和的两倍。



左图：未嫁接模型中的两个边缘瓣。
中间：两个襟翼之间嫁接了褶皱。
右图：展开褶皱后，可以在纸上看到襟翼两端之间的实际距离。

看起来，我们应该可以把襟翼合在一起来填满这个新空间（因为要设计出有效的模型，我们希望尽可能地把特征靠近）。但我们是否真的能利用这个空间呢？

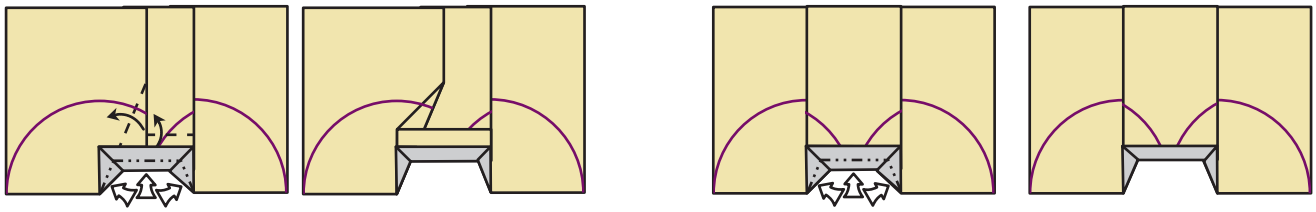


我们可以将襟翼移向对方，直到它们相碰。这样行吗？

这取决于我们如何使用襟翼。假设我们想在折叠后将襟翼的尖端完全保留在纸上。然后，我们可以将原边向上折叠并拉伸折痕，如下左图所示。拉伸后，襟翼尖端之间的最短距离（不离开纸张）是沿着下图所示的红色路径。其长度仅为理论最大距离的 60%，即展开纸张后襟翼尖端之间的实际距离。

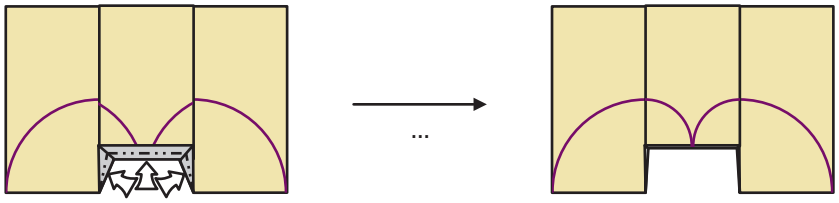
拉伸褶皱：通过创造负空间来增加瓣尖之间的距离。

如果我们能 100%跑完这段路程就好了，但这可能吗？我们可以做另一个拉伸动作来增加距离。但这种拉伸相当复杂。我们可以先将其中一个褶皱向左弯曲，使它变得更容易。这两种方法如下图所示。



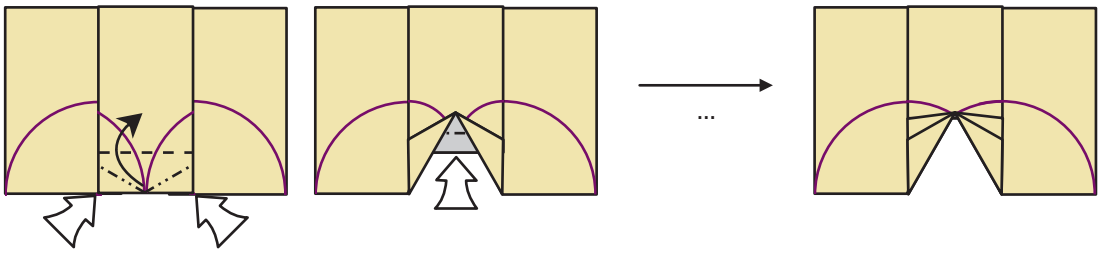
左：更复杂的拉伸。右图：创造同样的负空间，但对左侧的折叠稍作调整，使纸张对称。

如果我们继续上面右边最简单的拉伸，我们可以继续做越来越小的拉伸。这个过程的理论极限是一个具有矩形切口的形状，其上限是原始边缘。通过足够的弯曲，我们可以越来越接近这个形状，从而越来越接近理论最大距离的 100%。



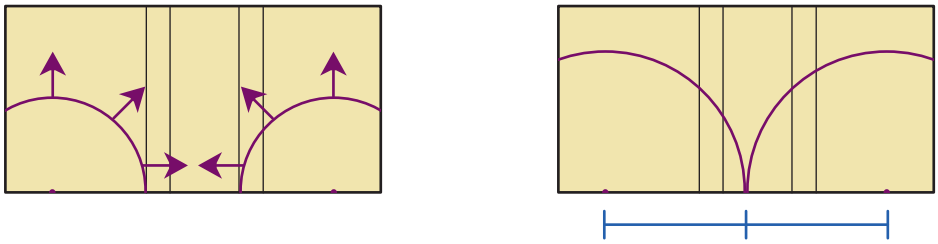
考虑到初始拉伸，理论极限是矩形。

但我们可能并不想要一个矩形切口，所以我们会考虑另一种初始拉伸的可能性，即原始边缘形成一个等边三角形的上半部分。有了足够的折叠，我们就可以进一步拉伸，使负空间任意接近等边三角形。我在这里说（没有证明），这在一般情况下是可行的：对于任何初始拉伸，都有一个进一步拉伸的序列，其极限会产生一个与初始拉伸的原始边缘形状完全相同的切口。事实上，这并不局限于垂直于原始边缘的平行褶皱，但我们在这里将使用这些例子。



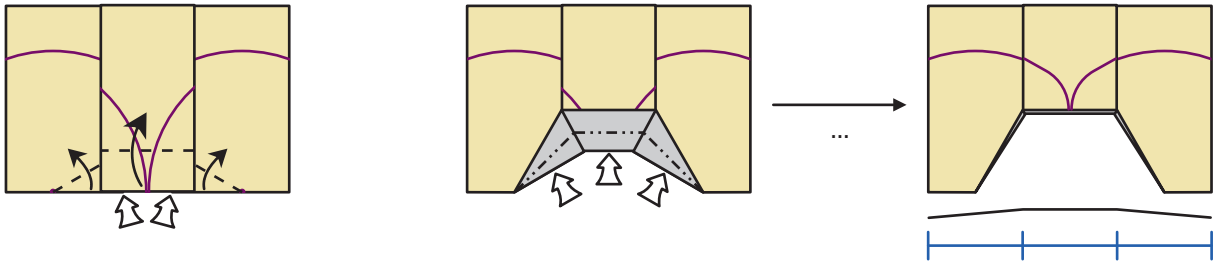
无论最初的拉伸幅度是多少，我们都可以任意制作出接近原边形状的切口。

我们可以尝试另一种方法：在添加褶皱后不将襟翼合拢，而是将襟翼加宽，以弥补缝隙。



伸展襟翼，直到它们接触。

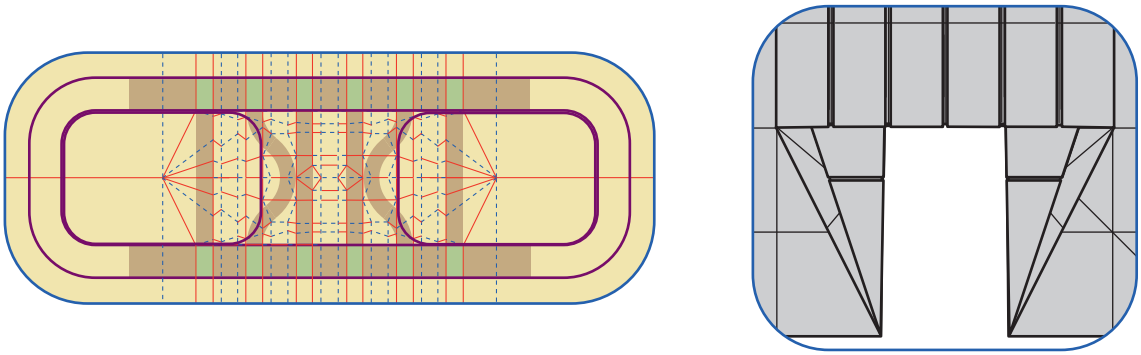
让我们再次对折纸张，尝试以不同的方式拉伸。(我们要吸取上次实验的教训，这次要对称折叠）。这次我们要折出一个正六边形的上半部分。



与之前一样，拉伸的极限会产生一个负空间，其极限位于原始边缘。请注意，拉伸后襟翼两端之间的总距离与上一页所示的展开纸上的距离相同。

仅是这里展示的折叠配置就有无数种可能性： 我只展示了几个比较简单的选项。侏儒 "包含一个用于分离腿部的拉伸装置--见步骤 51 至 63。由于以下三个原因，腿部拉伸是一个不错的选择：

- 纸腿需要在水平方向上分开（换句话说，纸基不是单轴的）；拉伸自然会产生负空间，从而保持这种间隙，如上面的三个例子。
- 褶皱会在纸张上向远离纸脚的两个方向传播，因此，如果我们保留并利用褶皱，而不是修改或终止褶皱，折叠就会更容易（见后面两节）。
- 虽然纸张排列的某些区域非常受限，但纸张中央的纸腿褶仍有很大的水平余地（见下图左侧）。这意味着，对于每一个折叠，我们都可以选择拉伸或保持折叠，任选其一。其他方法没有这种灵活性，因此折叠起来也更复杂。

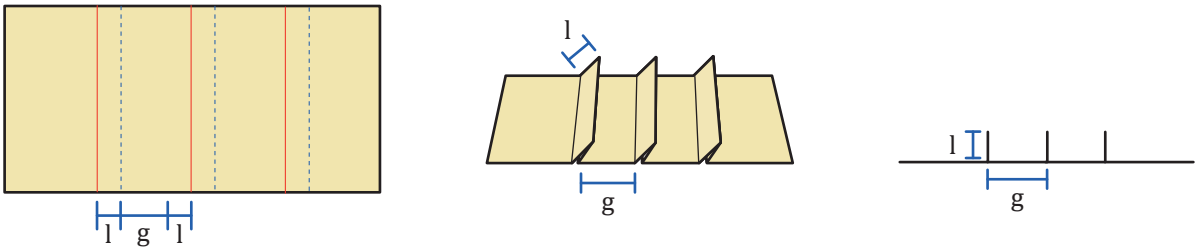


折叠模型和折叠底座，展示了拉伸制作斗殴侏儒腿部的过程。

折叠转换

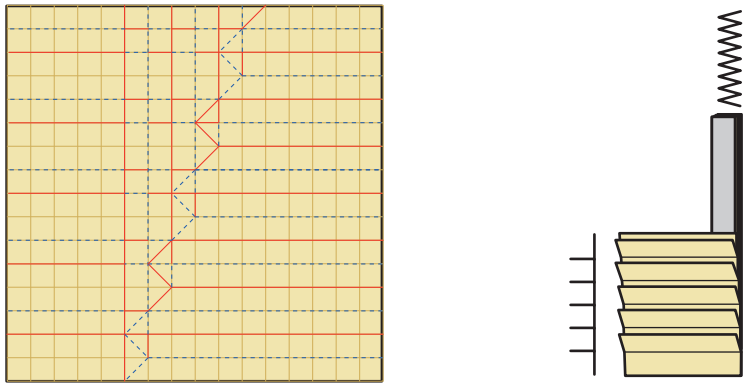
拉伸相对简单，因为它可以保持褶皱不变，但这限制了它的实用性。如果我们能通过变换来修改褶皱，使其具有不同的宽度或方向，我们就会有更多的选择。我把这类变换称为褶皱转换器。褶皱转换器具有结构性和技术性。它们在箱褶设计中很常见，因为网格的使用为使用准确的褶皱提供了有价值的参考。

我们将观察褶皱的横截面，并将其表示为一个棒状图形。这个棍棒图形的叶缘间距规则，从一根茎上发出。我们称这种图形为梳子。我们将用两个变量来量化梳子：l，每个叶缘的长度（每个褶皱的宽度）；g，叶缘之间的距离（褶皱之间的空间）。我们将把已知这些值的特定梳状结构称为 l,g 梳状结构。例如，下一页顶部的褶皱结构就是 1,2 梳子。请注意，在某些情况下，重要的只是 l/g 比值，但在这里，即使 l/g 比值相同，我们也必须区分两种不同的梳子。



CP、折叠图案和 1,2 梳子（l=1，g=2）的棒图。请注意，折叠图案上的峰值之间的距离是 4：一般来说，这个距离是 2l+g。

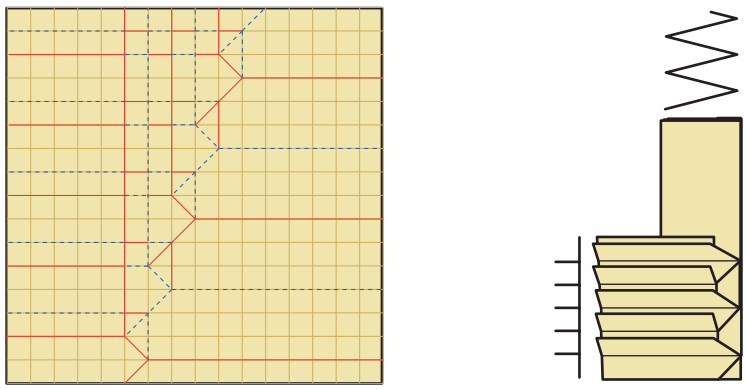
最常见的折痕转换器之一是将 1.1 折痕转换为 1.0 折痕（无空格折痕），方法是将新折痕折成 90° 角。这意味着它们沿着图案区域的边缘运行，而不是垂直于图案区域。下面的折痕图案就说明了这种方法。



CP 和折叠显示 1.1 梳齿变为 1.0 梳齿。

1.0 梳子（或任何 x.0 梳子）只是一连串等距的山峰和山谷交替折叠。这种结构在复杂的折纸中很常见：你可以在本书的几个折纸图案中看到这种类型的大段。这意味着涉及 x,0 梳的折叠转换非常有用，因为它们可以更容易地整合到折纸图案的其他部分中。特别是，x,0 梳齿和 y,0 梳齿之间的转换非常常见，以至于有了自己的名称--水平移动（但请注意，水平移动也有其他形式）。

事实上，上述折叠模式有一个简单的修改，可以将 1,1 梳齿转换为 3,0 梳齿。如果反过来使用，这是一种一次性完成小折叠的有效方法（而不是使用两个单独的折叠转换，后者效率较低）。不过，我不记得在图案中见过这种方法。你可以自己试验一下，看看是否能派上用场。

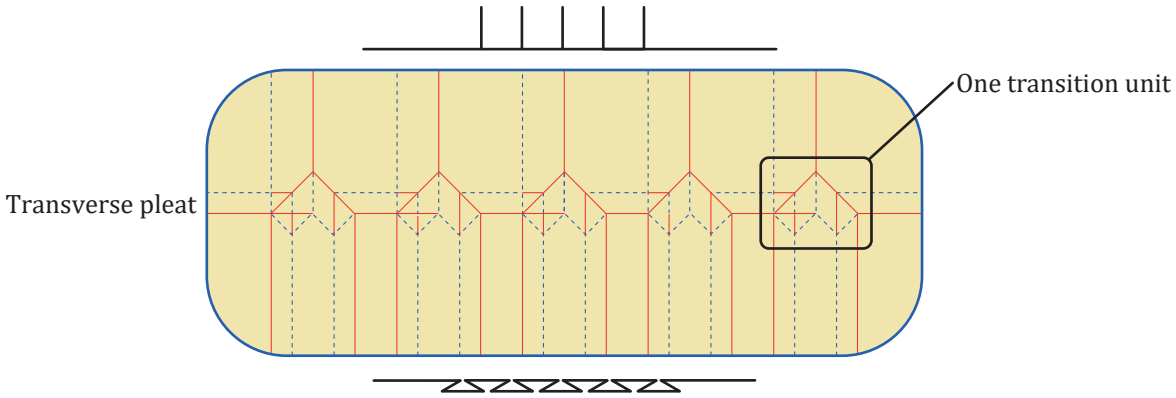


折痕模型，显示 1.1 梳子向 3.0 梳子的转变。

前两种折叠转换器虽然易于折叠，但会造成大量的纸张浪费。CP　包含垂直中心折叠，沿着顶部原始边缘将左右区域分开，但左右区域并不需要分开。这意味着这些褶皱中的纸张被浪费了，而且需要转换的褶皱越多，这个问题就越严重（可以制作无损版本，但通常褶皱不在网格上）。探讨这个话题很快就会变得非常专业，因此值得单独关注，不应在此强行插入）。

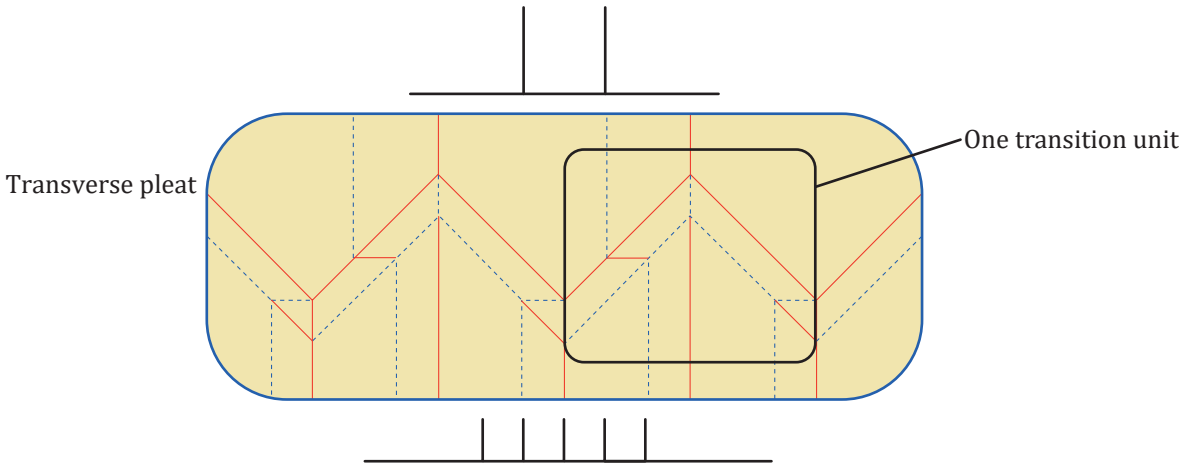
在制作两个指向同一方向的梳子时，也会产生类似的代价：一个新的小折叠与梳子折叠交叉，通常是直角。我将其称为交叉褶皱，沿着交叉褶皱的最小重复褶皱图案称为过渡单元（见下图）。交叉褶皱的具体尺寸取决于所转换的梳子，但通常所需的最小宽度小于两个梳子长度中较大者。交叉折叠的宽度并不取决于图案区域的大小，因此当用于有许多小图案折叠的图案区域时，与之前的例子相比，制作这种折叠转换器所需的额外纸张量很小。

小矮人包含两个不同的褶皱转换器。第一个将编织顶部的褶皱（不是梳子）转换成 1.1 梳子。这个褶皱的步长为 88 到 95 步。



矮人斗士盔甲顶部的简化褶皱图案。垂直褶皱
底部的垂直褶皱是编织，顶部的垂直褶皱（1,1 梳）通向头部，横向交叉褶皱包含在转换过程中丢失的纸张。
横向水平褶皱包含在转换过程中丢失的纸张。

在矮人中使用褶皱转换器的另一个效果是将 1.1 的梳齿放大为 2.2 的梳齿。这可以在第 96 步至第 100 步中看到。



小矮人头盔底部的简化折叠图案。这里的交叉折叠是之字形的。

这两个褶皱转换器用于盔甲顶部和头部之间的过渡。这是一个明智的选择，因为与盔甲褶皱相比，我们需要更大的褶皱来制作面部和头盔边缘。

层压转换器组合

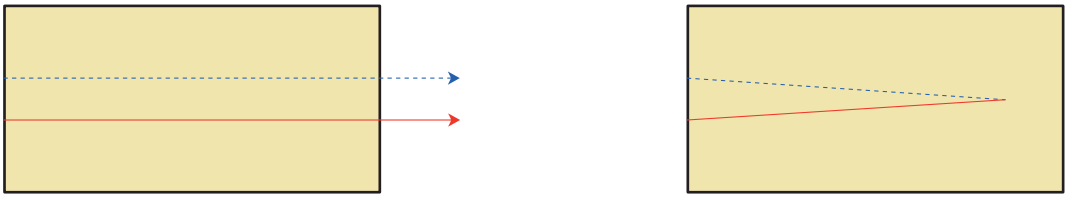
折叠转换器是折纸工具箱中的一个巧妙小工具，可以连续使用，制作出更多的工具。例如，上面的 CP 可以用来将 2.2 的梳子转换成 4.4 的梳子，然后再转换成 8.8 的梳子，以此类推。在具有相同升/克比的梳齿之间进行任何转换时，都会出现这种有用的放大。

关于折叠转换器的注意事项：它们需要梳状或其他规则的折叠结构，这降低了它们的通用性。这与本章中的其他两种方法形成鲜明对比，这两种方法不要求折叠的规则性--每个折叠的宽度和折叠之间的空隙可以不同（事实上，它们甚至不要求平行折叠）。

折叠终止

如果我们只希望在某个特定区域产生褶皱，那么找到在一端或两端终止褶皱的方法就很有意义。这将彻底消除褶皱超出预定区域的问题。

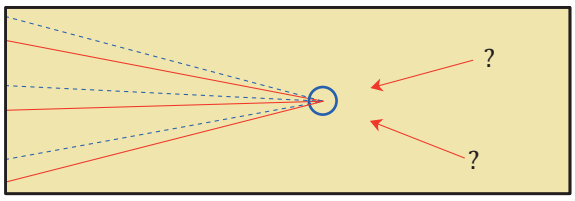
褶皱无限延伸的原因在于它们是平行的。正如我们在本章开头所说的那样，情况并非总是如此，事实上，我们有充分的理由不使用平行褶皱：非平行线总是相交。因此，如果我们能修改褶皱的山折或谷折（或两者），使它们相碰，那么褶皱就会结束。



当且仅当直线不平行时，它们才会相交。

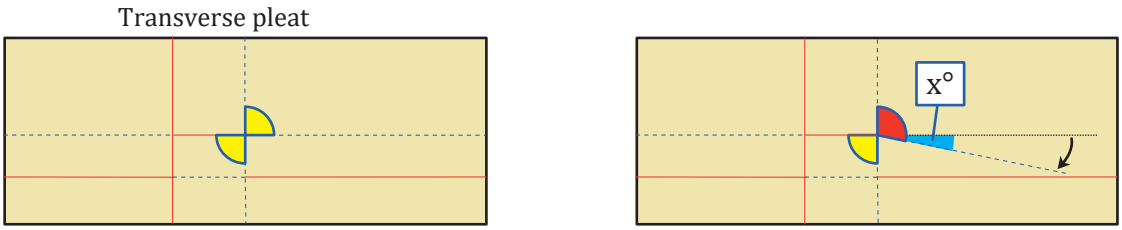
径向褶皱的终止

一个相当令人满意的方法是让几个折叠汇聚到一个点。我称这一点为所有褶皱的终止点。每次折叠都会给终点处的折叠带来山谷和山峰的折叠，但众所周知，在平折折纸中，山谷的数量和山峰的数量之差总是两个（前川定理）。这就意味着，如果我们希望区域是平的，那么在终点处必须有其他折叠。因此，自然是使用折纸图案中现有的点作为终点，而不是创建一个新的山峰。



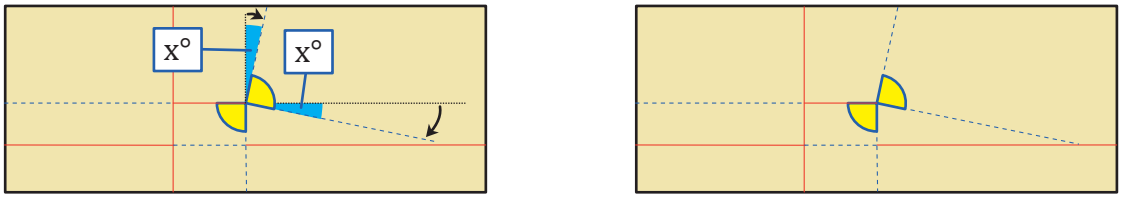
终止点：该顶点周围必须至少有两个其他折叠点。

但我们如何改变折叠的角度呢？与折叠转换器一样，我们需要创建一个新的交叉折叠。让我们以单个折叠为例，看看能否只改变一条折叠线的角度。在左下图中，注意中心的顶点，垂直十字折线与水平折线在此交叉--两个黄色的角度是 90°。如果我们尝试将水平谷折向右旋转，纸张就不会平整。这是因为围绕平折顶点的其他角度之和必须等于 180°（川崎定理）。



左图：两个黄角各为 90°。右图：如果右边的山谷折痕顺时针旋转 x°，那么红色的角度就会过大 x°，从而导致图案折叠不平。

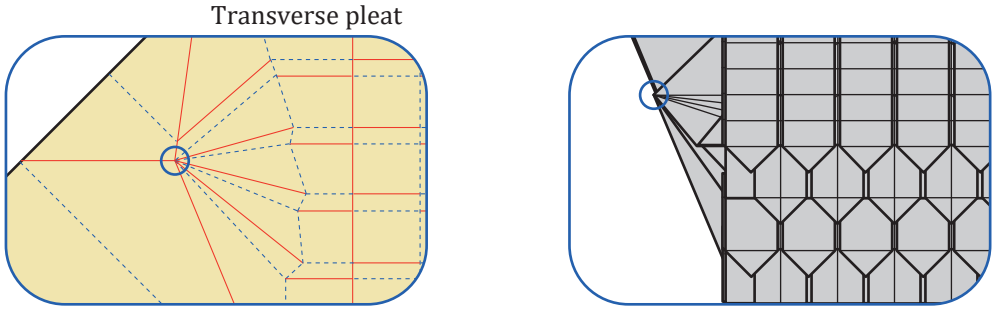
要解决这个问题，至少有一个垂直谷也必须旋转。在下面的例子中，顶谷旋转后，纸张可以折叠平整。



左： 顶部的山谷也可顺时针旋转 x°。右图： 中央山顶可折叠成平面。

每个褶皱的角度都会发生相同的变化，这意味着交叉褶皱会在褶皱上移动，无法很好地与褶皱图案的其他现有区域对齐（除非旋转角度的选择非常谨慎）。在矮褶中，径向褶终止用于完成编织两侧的褶皱，如步骤 66 至 69 所示。这种技术适用于模型的这一部分，因为

- 这些部分是使用褶皱的箱形褶皱编织与不需要褶皱的 22.5°几何臂之间的过渡。
- 编织靠近原边，因此产生的角度不规则的褶皱可以立即从纸上去除，以免影响 CP 的其他部分。
- 这里只使用了四个褶皱。径向褶皱的终止应仅限于少量褶皱，因为大量的窄褶皱会在终止点产生很大的应力（即撕裂的风险相对较高）。

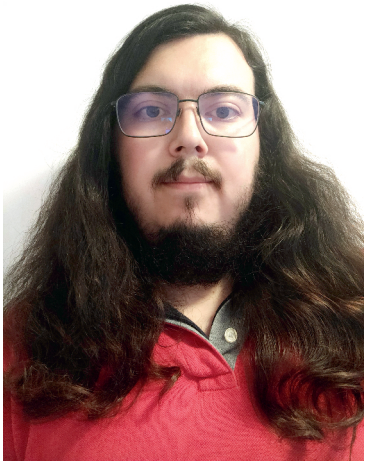


小矮人盔甲左侧的简化折叠模型。两张图片中的点都被圈了起来。
请注意 "CP "折叠图案中十字形折叠的 "之 "字形山谷。

径向折叠终止可能是本章介绍的三种技术中最难准确折叠的一种，也是最不常用的一种，这一点不足为奇。但它具有极大的灵活性，与局限于盒式折叠的方法相比，它能让你创造出更多的有机形状。探索这一技巧，并将其用于自己的折纸中，创造出具有全新风味的图案设计。

Contribution

Florian Videau



弗洛里安在检查本书中的图表时表现出色，我非常感谢他花时间找出我所有的错误！他还提供了一些快速检查图表的技巧，这些技巧不仅对图表作者有用，而且对任何试图按部就班地学习图表的人都很有用：

"作为一名软件工程师，我喜欢了解事物的工作原理，也知道清晰详细的说明有多么重要。当我使用图表折叠模型时，我总是注意三件事：

- 箭头和折痕。

- 解释步骤的文字（如果是用我能理解的语言写的）。

- 可以看到预期结果的下一张图片。

所有这些元素必须匹配，否则就会出错。在图表布局中，我尝试查看这三个元素中哪一个与其他两个不匹配，以了解需要更正的地方。有时三个元素都匹配，但一旦我拿到纸，我就必须花很多时间进行测试和调整，才能明白需要做什么，这对我来说说明说明不够清晰，我就会想办法让它们更容易理解"。

MICHAEL NGUYEN

Michael Nguyễn 是一位德国传播设计师和信息艺术家，在科维德大流行之初，他发现了自己对折纸的热情。他专门从事人形折纸的重新诠释和设计，曾多次获得 Joisel 奖 "形象诠释 "类的提名和奖项，最近在柏林举办了他的首次艺术家展览，并与志同道合者一起举办了在线折纸工作坊。

迈克尔探索各种方法，通过自由折叠引入新的细节和纹理，有效地重新排列现有 PC 的整个结构部分。这种方法使他能够获得与原始设计大相径庭的效果，即使底座是相同的。受到埃里克-乔塞尔（Eric Joisel）、渡边圭（Kei Watanabe）和江丁（Giang Dinh）作品中丰富的雕塑感的启发，迈克尔使用雕塑技术来增强设计的真实感，并为纸张注入生命力。

他对人类情感的表现力与历史、文化和宗教领域的叙事之间的交汇十分着迷。迈克尔最近完成了一个关于折纸术语的学位项目，他希望通过折纸与人们建立有意义的联系，并鼓励公众超越对折纸褶皱的传统认知。

Instagram: @mayuncchigami

我非常感谢花时间测试这本书中图表的每一个人，看到他们的创造性诠释总是非常鼓舞人心。例如，我很喜欢桑普里特-曼纳（Sampreet Manna）利用 "赛琪"（Psyche）的粗糙边角添加的额外爱心、戈尔-桑切斯（Goar Sanchez）的 "九头蛇"（Hydra）的四脚姿势以及高拉夫-阿萨瓦莱（Gaurav Athavale）的 "蜘蛛"（Spider）的近乎异形的姿态。

与其把这些照片留给自己，不如在这多彩的页面上展示一些折页者的非凡才华，是他们让这本书成为可能。感谢大家。

GOAR SANCHEZ

JAVIER HERNÁNDEZ AHUAT

SAMPREET MANNA

ROMAIN BONTEMPS

GAURAV ATHAVALE